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THE DEVELOPMENT OF SYSTEMATIC PETROGRAPHY IN THE NINETEENTH CENTURY.

Part II.[1]

Beginning of the microscopical era.— Having presented the state of systematic petrography up to the time when the polarizing microscope became the instrument of prime importance in the investigation of rocks, we now proceed to the study of the more recent schemes of classification, based upon the larger knowledge. For all systems thus far reviewed, it must be recognized that ignorance of the characters and relationships of many rocks rendered a comprehensive and logical scheme impossible. The frame work of system was necessarily constructed without full knowledge of the applicability of some of the factors employed. With the polarizing microscope and improved methods of chemical analysis this condition has now disappeared, and while the time may not be ripe for unbiased criticism it is plain that modern systems of classification must ultimately be judged with regard to the greater and almost perfect knowledge of the actual characters of rocks enjoyed by the authors of those systems. The responsibility for the choice of factors suitable for the construction of a comprehensive system and for a logical, consequent, and consistent application of those factors clearly increases with knowledge of the objects to be classified.

The microscopical study of rocks, continuing for nearly four

[1] Continued from p. 376.

decades with ever improving facilities and methods, has added a vast store of knowledge concerning the characters of these objects. Revelations concerning the composition of types long known have often been astonishing. The essence of rock structures has been made clear. The uttermost parts of the earth have been searched, and many new and interesting varieties have been discovered—not all in distant fields, but often close at hand. For new structures and new types, new terms have been proposed, and the nomenclature has thus expanded enormously. In the light of new discoveries, old conceptions have given way to new ideas, and the terms expressing them have yielded to new ones, or, in too many cases, the old nomenclature has been retained with new definitions. But while the last third of the nineteenth century may be termed the microscopical period of petrography, great additions to our knowledge of rocks were also made in this period on all older lines of study, and especially by quantitative chemical analysis and by investigations as to the modes of occurrence and the field relations of different rocks.

This review, which deals with system, must trace the application of new or revised principles to classification during this period of rapid addition to knowledge. It is perhaps quite natural that the greater part of the systematic advance was in partially worked out revisions of old schemes—grafting some new idea to the old trunk. It is also natural that the greatest work has been in the field to which the microscope has been particularly applied, so that at times petrography has been treated as though narrowed to the microscopical petrography of igneous rocks.

While the flood of microscopical rock studies was at its height, it was manifestly impossible for anyone to do more than to present the new information in comprehensive form, without finished attempt to apply it to the systematic arrangement of rocks. It is with this condition in mind that the important works upon microscopical petrography, issued in the decade 1870 to 1880, must be judged. Their actual effect upon the systematic science was, however, very great, from the mere fact

that they exerted a controlling influence over the usage of a multitude of workers.

Ferdinand Zirkel, 1873.— In 1873 appeared *Die mikroskopische Beschaffenheit der Mineralien und Gesteine*, by F. Zirkel. The systematic point of view occupied by this authority at this time is expressed in the following tabular analysis of his larger divisions of rocks:

A. Non-clastic rocks ("Nicht-klastische Gesteine").
  I. Simple ("Einfach").
  II. Composite ("Gemengt").
    1. Massive ("Massig").
      a. Feldspathic ("Feldspath-haltig").
      b. Non-feldspathic ("Feldspath-frei").
    2. Schistose ("Schieferig").
B. Clastic-secondary rocks ("Klastische-deuterogene-Gesteine").

Comparing this scheme with that of the *Lehrbuch der Petrographie*, we find that the microscope has convinced Zirkel that *crystalline* cannot be appropriately opposed to *clastic*. He also believes that *original* cannot be used for non-clastic rocks because they have been discovered to be at the present time in part composed of alteration products. He therefore falls back on a negative term, *nonclastic*, admitting that it is indefinite— "misslich." *Massive* is defined as *not schistose, in larger part granular*— "nicht geschiefert, zum grossen Theil körnig."

The work deals mainly with the *feldspathic, massive, composite, non-clastic rocks*. These are subdivided as follows:

I. Orthoclase rocks.
  1. With quartz.
  2. Without quartz, with or without plagioclase.
  3. Without quartz, with nephelite (or leucite).
II. Plagioclase rocks.
  1. With hornblende.
  2. With augite.
  3. With diallage.
  4. With hypersthene.
  5. With mica.
  6. With olivine.
III. Nephelite rocks.
IV. Leucite rocks.

The use of the soda-lime feldspars—oligoclase, labradorite, and anorthite, as factors in the subdivision of feldspathic rocks, found in the *Lehrbuch*, had been shown by the microscope to be an error, and it disappears without comment. The mineral composition of rocks is here applied to their classification in a qualitative way almost exclusively. Zirkel remarks: "To the non-feldspathic, non-schistose, composite rocks belong among others: eclogite, tourmaline rock, olivine rock, eulysite and saussurite-gabbro." Of these only three are described and within a compass of two pages.

The age distinction in classification of igneous rocks is freely characterized by Zirkel as unnatural and undesirable and it is not formally recognized in this work as it was in the *Lehrbuch*, yet he could not see his way to carry out the reform necessary to its rejection and retained in description many of the duplicate terms based on it.

Structure and *crystalline condition* were not given a defined rôle in Zirkel's new system, but in practice the granular, porphyritic, fluidal and glassy forms were distinguished.

A. von Lasaulx, 1875.—The *Elemente der Petrographie*,[1] by A. von Lasaulx, issued in 1875, is another attempt to utilize the results of microscopical study of rocks in their classification and description. Von Lasaulx believed that since there are no true rock species, and since transitions in all directions are most common, classification must consist in the establishment of *types*, about which should be grouped the intermediate kinds of rocks. He announced as his guiding principle that rocks must be classified upon the basis of simple, definitely known and easily recognized, morphological properties. Genetic criteria did not seem to him applicable because always more or less hypothetical and in some cases entirely so. He, therefore, discards the primary classification of rocks on genetic principles, advocated by von Cotta and others, and returns to von Leonhard's elementary division into *Simple*, *Composite* and *Clastic* rocks, omitting the *Apparently simple* class as no longer necessary.

[1]*Elemente der Petrographie*, Bonn, 1875, pp. 486.

The morphological characteristic of rocks chosen by von Lasaulx as most applicable to the systematic subdivision of the classes mentioned was the degree or distinctness of crystallinity, which is surely the most variable of all their properties, and hence least adapted to the formation of well-defined groups. The major divisions formed by von Lasaulx are as follows :

Simple Rocks :

- A. Non-crystalline (amorphous) or semi-crystalline.
- B. Crystalline granular.
  - *a*. Really simple.
  - *b*. Rocks forming transitions to Composite group through the appearance of vicarious constituents (*e.g.*, amphibolite, serpentine, etc.).

Composite Rocks :

- A. Massive.
  - *a*. Amorphous, glassy (obsidian, etc.).
  - *b*. Semi-crystalline (including vitrophyres).
  - *c*. Crystalline.
    1. With abundant glassy base (basalt, etc.).
    2. With microaphanitic more or less individualized groundmass.
       - *aa*. Groundmass alone (felsite, etc.).
       - *bb*. True porphyries (felsite-porphyry, etc.).
    3. Rocks which are almost completely crystalline, mainly pseudo-porphyritic, etc. (phonolite, hornblende-andesite, etc.).
    4. Crystalline granular.
       - *aa*. Feldspathic (granite, etc.).
       - *bb*. Non-feldspathic (Greisen, eclogite, etc.).
- B. Stratified Rocks :
  - *a*. Feldspathic (gneiss, etc.).
  - *b*. Non-feldspathic (mica-schist, etc.).

Clastic Rocks :

- A. Semi-clastic (clay slate, kaolin, tuff, etc.).
- B. Purely clastic.

Mineral composition is applied as a factor to produce the commonly recognized rock types within these groups. It will be noted that many of the divisions above mentioned are not only quite indefinite but they are, also, inconsequent. Thus, three out of four divisions of *crystalline massive* rocks are but *partly* crystalline.

Meteorites are described by von Lasaulx in an appendix.

Concerning this treatment he remarks that it is the first time that cosmic rocks have been given a place in a text-book of petrography, but that it seems useful, for purposes of comparison, to have them described in the same work with the terrestrial rocks.

H. Rosenbusch, 1877.—Another important summary of the results of the microscopical investigation of rocks appeared in 1877, under the title *Mikroskopische Physiographie der massigen Gesteine*, by H. Rosenbusch. There was in this work but slight discussion of principles of classification, and the only new factor of note in the system used is the idea expressed in the title, which requires some explanation. All rocks were divided into two classes:

I. Massive rocks ("Massige Gesteine").
II. Stratified rocks ("Geschichtete Gesteine").

A class of Metamorphic rocks was not considered feasible.

"Massive" and "stratified," as used by Rosenbusch in this connection, do not refer to rock textures, as one might suppose from the historic use of the terms; for this primary division was avowedly intended to express an idea, first brought out by Lossen (which will be referred to more fully in a later section of this review), that the most important relation of rocks is the formal one to the earth sphere. Rocks may be considered as having been formed, either at the surface under the influence of gravity, in more or less concentric shells or strata, or, in eruptive bodies of irregular shape and position not determined by gravity. Under this conception all rocks are either stratified or massive. Massive rocks in this sense are also eruptive rocks, but Rosenbusch chose to use the former term in systematic petrography because free from the genetic conception involved in the latter. In view of the evolution of this master's ideas, presented in later works, his language will be quoted:[1] "The former name is to be preferred because it refers only to an undeniable form of

[1] "Der erste Name ist vorzuziehen, weil er sich lediglich auf eine unläugbare Erscheinungsform bezieht und keinerlei irgendwie geartetes Präjudiz über die genetischen Verhältnisse involvirt."

occurrence, and involves no possible prejudice concerning genetic relations."

The controlling criteria in the further construction of Rosenbusch's scheme will be apparent from the following partial tabular statement :

Massive rocks.

A. Orthoclase rocks.

a. Older.

I. Quartzose.

1. Granular = Granite Family.
2. Porphyritic = Quartz porphyry Family.
3. Vitreous = Felsite-Pitchstone Family.

II. Quartz free (3 families similar to those above).

b. Younger.

I. Quartzose.

1, 2. Granular or porphyritic = Liparite Family.

3. Vitreous = Family of the acid glasses.

II. Quartz free (with families as above).

The other large groups are the following :

B. Orthoclase-Nephelite, or Orthoclase-Leucite rocks.

C. Plagioclase rocks.

D. Plagioclase-Nephelite, or Plagioclase-Leucite rocks.

E. Nephelite rocks.

F. Leucite rocks.

G. Non-Feldspathic rocks. Of the Non-feldspathic rocks Rosenbusch remarked[1] that they were all rich in olivine, and might therefore be called *Olivine rocks*.

Each of these groups has Older and Younger divisions, and, within these, families, established in a manner similar to that given for the orthoclase rocks.

In this arrangement *mineral composition* is used, as in Zirkel's system. The *age distinction* is applied without discussion. *Texture* is given a prominent rôle, and *chemical composition is not used*.

Fouqué and Michel-Lévy, 1879.—The first effects of the microscopical study of rocks upon petrographic system in France may be seen in the *Minéralogie micrographique*, by F. Fouqué

[1] "Sie sind sämmtlich reich an Olivin, daher kann man sie kurz als Olivingesteine bezeichnen."

and A. Michel-Lévy, which was published in 1879. While presented as an "Introduction à l'étude des roches éruptives françaises," there is in this work some discussion of principles of classification, and a tabular view of the scheme in use by the authors. Although the system in question has not had much influence except in France, it is of interest from certain new and peculiar conceptions which are given classificatory value in it.

It is first to be noted that Fouqué and Michel-Lévy abandon almost entirely the system of Cordier. Although affirming that rocks are simply the most abundant natural associations of minerals ("les roches ne sont autre chose que les associations minérales naturelles le plus fréquentes"), they proceed to their arrangement under the stated principle that a rational classification of rocks in general must be based upon the following three fundamental characters, namely: (1) The mode of formation; (2) the geological age; (3) the specific mineral properties. The last named character comprises: (*a*) the nature of the integrant minerals; (*b*) the structure of the rock.[1] By the application of the first factor they separate eruptive rocks from those deposited as sediments or as vein filling. By the factor of geological age (the applicability of which is not discussed) they distinguish clearly — "nettement" — between pre-Tertiary and Tertiary or post-Tertiary rocks. It is believed that the same types occur in both groups, following approximately the same order of eruption, with predominance of basic rocks and a tendency to the vitreous condition in the most recent occurrences. In these respects the new French system is practically like others which have been reviewed, but in the use of *structure* and *mineral composition* for the main framework of their system, Messrs. Fouqué and Michel-Lévy apply certain peculiar conceptions requiring some analysis.

Considering that in practically all eruptive rocks there have been two (or more) distinct periods of formation of the primary

[1] "Un classement rationel des roches, en général, doit s'àppuyer sur les trois caractères fondamentaux suivants: 1° le mode de formation; 2° l'âge géologique; 3° la spécification minéralogique. Ce dernier caractère comprend: (*a*) la nature des minéraux intégrants; (*b*) leur structure d'association (structure de la roche.)"

mineral grains, these authors proceed to give a strangely artificial weight to the products of the second period, both in definitions of structure and in classifying rocks by mineral composition. The structures of eruptive rock applied in classification are brought under two groups : "structures granitoïdes" and "structures trachytoïdes." The essential difference between the two is conceived to be that in the granitoid the grains of the two periods of consolidation resemble each other, because of similar conditions of consolidation in the two periods, while in the trachytoid structure there is a marked difference between the two products as a result of changed conditions in the later period. In the rocks commonly called granular it is thought that two generations of mineral grains of approximately the same formal character may usually be recognized. Where no distinction can be made it is rather paradoxically assumed that the grains all belong to the *second* period. But it is to be noted that without this assumption the scheme of Fouqué and Michel-Lévy, as it stands, could not classify such a rock. Porphyries in which the groundmass is granular are, from that fact, classed with perfectly granular rocks.

Under the granitoid group of structures three varieties are recognized: (1) Granitoid proper, in which each individual grain has approximately equal dimensions in all directions, variation in size being disregarded; (2) pegmatoid, the regular or graphic intergrowth of two minerals of simultaneous crystallization; (3) ophitic, characterized by elongated feldspar crystals, and forming a transition to the microlitic structure.

The trachytoid group of structures has likewise three varieties: (1) *Type pétrosiliceux*, characterized by bands of minute spherulites and the presence of the mysterious substance petrosilex or microfelsite; (2) *type microlithique*, characterized by microlites of feldspar, and of other minerals; (3) *type vitreux*, characterized by predominance of amorphous substance.

In explaining the microlitic type the authors point out that their synthetic experiments prove that such microlites are products of *pure igneous fusion*, indicating to them a fundamental

difference between the trachytoid and the granitoid structures, since they believe that certain mineralizing agents ("agens minéralisateurs") are necessary to the latter development.

This view of rock structures makes the shape of the mineral grains all important and casts aside the formal relationship prominent in the porphyritic structure as of little value. The equidimensional *grain* and the elongated *microlite* are placed in fundamental opposition to each other.

The mineralogical composition of rocks is applied for their classification in a qualitative way, similar in some respects to that adopted by the German petrographers, but with the all important modification that *only the minerals of the second period of consolidation are considered.* Such a principle may be designated as subjective, extremely unnatural and highly artificial. There is in this system no attempt to express the chemical composition of the rock in terms of its minerals, for in some cases all the minerals of a rock are used in its classification, where there was no *first* period of consolidation, and in other cases only a small portion of the constituents, as in porphyries with abundant phenocrysts and microlitic groundmasses. Since in porphyries this portion of second consolidation bears no definite quantitative relation to the mass as a whole it must often happen by this system that rocks of widely different chemical composition will be brought together and, conversely, that rocks of the same chemical character and even of the same magma will at times be separated. For example, certain intrusive quartzose hornblendic diorite-porphyries of the Rocky Mountain region, in which hornblende and plagioclase are developed entirely in phenocrysts, would fall among the microgranulites while their granular equivalents would be quartz-diorites. It is also clear that all but granular rocks would be classified in this scheme by their most obsure constituents, often to the neglect of every prominent megascopic character, and systematic petrography would become purely a microscopical science. It is interesting to recall at this point the principle announced by these authors and quoted above that a rational classification of rocks must be

based upon the " fundamental characters " whose application has been reviewed,

In practice, Fouqué and Michel-Lévy give the first importance to the colorless constituents, quartz, feldspars, feldspathoids, etc., to produce series within which the ferromagnesian minerals are used to make subdivisions. The existence of certain phenocrysts is recognized, in the naming of rocks, in a few cases only.

The petrographic system for eruptive rocks elaborated by Fouqué and Michel-Lévy in 1879 has remained the system of France to the present time, with but slight change.

In 1889 Michel-Lévy compared the results of their system with those of the Rosenbusch system, soon to be discussed, in a work entitled *Structures et classification des roches éruptives.*[1] This

[1] Paris, 1889, pp. 93.

discussion presented no new propositions of note excepting a plan of expressing the structure and mineral composition of any given rock by a formula. The principles which must govern the classification of eruptive rocks are concisely stated as follows :

> It is neccessary to base the classification and nomenclature of rocks upon positive facts, independent of all hypothesis. Modern petrography possesses the means to accomplish this end, since the principal structures or modes of association of the minerals are well known and the minerals themselves may be determined with precision. It is, then, exclusively structure and mineral composition which must be relied upon in the classification and nomenclature of rocks.[1]

It is to be remarked, once more, that chemical composition is not taken into account by Michel-Lévy, either directly or indirectly, since the partial mineral composition used by him in classification is clearly not an expression of the chemical composition of the magma nor of any definite part of it. The substance classified is not the rock but merely that variable portion

[1] "Notre conclusion, ... est qu'il faut baser la classification et la nomenclature des roches sur des faits indépendants de toute hypothèse, et de nature positive. La pétrographie moderne dispose de moyens suffisants pour atteindre ce but sans hésitation : on est d'accord sur les principales structures d'association des minéraux des roches ; on sait déterminer ces minéraux avec précision. C'est donc *exclusivement* sur la structure d'association et sur la composition minéralogique que nous persisterons à nous appuyer pour classer et nommer une roche." *Loc. cit.*, p. 87.

of the rock which the investigator judges was in a fluid or pasty condition at the beginning of the second period of consolidation —the "pâte."

Samuel Allport.—During this period in which Zirkel, Rosenbusch, Fouqué and Michel-Lévy were formulating more or less distinct advances in systematic petrography, the English students of rocks made but slight positive contributions in this direction. The condition of the science may be best appreciated by reference to the various short discussions of principles of classification by Samuel Allport. This careful investigator often pointed out the fallacy of the age distinction, so clearly illustrated by the long-known ancient lavas of the British Isles, and also the importance of Judd's discovery of the intimate relationship of coarsely crystalline and volcanic rocks. This was cited to disprove the idea that a sharp line could be drawn between the Plutonic and Volcanic rocks. But Allport considered it premature to suggest any great changes either in classification or nomenclature.

Clarence King, 1878.—In America no original contributions to systematic petrography were made prior to the microscopical period. The earliest use of the knowledge gained in that period was probably by Clarence King,[1] whose appreciation of its value led to the report upon the Microscopical Petrography of the 40th Parallel rocks by Zirkel, and who, also, applied certain supposed facts resulting from microscopical research in his own discussion of the classification of volcanic rocks. The proposition referred to has had little influence upon petrographic system, but has a certain importance from the standpoint of this review as illustrating again the dangers of applying genetic ideas in the classification of igneous rocks.

King accepted the law of Bunsen and the law of succession of volcanic rocks advocated by von Richthofen, which have been stated. He also considered that "a sharp line is to be drawn between the so-called Plutonic rocks and the true igneous ones." The microscopical studies of which he had knowledge led him

[1] Report of the Geological Exploration of the Fortieth Parallel, I. *Systematic Geology*, pp. 705–25, Washington, 1878.

to the strongly stated conclusion that "all the volcanic rocks show abundant evidence of fusion in the presence of glass base and glass inclusions, while the group which is typified by granite never shows the slightest trace of the effects of fusion." All known characters of plutonic rocks are interpreted as proving them to be extreme products of the metamorphism of sediments. After discussion of the cause of generic differences of volcanic rocks, in which certain new hypotheses concerning magmatic differentiation are developed, King proposes the following systematic arrangement for the family of volcanic rocks, including therein all believed to be of truly igneous origin:

Genera.—(1) Propylite; (2) Andesite; (3) Trachyte; (4) Neolite. Expressions of time, according to von Richthofen's law of succession, and of depth owing to secular refrigeration.

Species.—Expressions of chemical differentiation by specific gravity of mineral ingredients, grouping under the law of Bunsen.

Three species only were recognized under each genus, representing respectively the quartz, biotite or hornblende, and pyroxene-bearing forms.

Varieties.—Expressions of range of texture according to predominance of secreted crystals, groundmass, or base.

M. E. Wadsworth, 1884.—Under the title *Lithological Studies; A Description and Classification of the Rocks of the Cordilleras*, M. E. Wadsworth published, in 1884, the first part of a projected comprehensive work, intended to present a new classification of rocks. This first part was devoted to a discussion of principles and the beginning of the descriptive portion. Wadsworth denounced all existing systems as highly artificial, and stated, as the basis of his own more natural system, the belief that "the older rocks now classed as distinct species are rocks that were once identical with their younger prototypes." "The order [of his system] will be to pass from the glassy to the most perfectly crystalline state; from the least altered to the most altered; from the most basic toward the most acidic; from the non-fragmental to the fragmental or clastic." He plunged at once into a description of ultrabasic rocks, without explaining the

proposed application of his asserted principle to the construction of a system, and no further portions of the projected work have appeared. It is plain that the basis of Wadsworth's conception is contrary to known facts of petrogenesis. A direct contribution to petrographic system is afforded by the proposition made by Wadsworth to group terrestrial and meteoric masses together, applying to them a single system and nomenclature. The descriptive portion of the published work is, in fact, mainly occupied with discussion of meteorites rich in iron. Wadsworth thus goes a step further than von Lasaulx, who treated meteorites in an appendix to his discussion of terrestrial rocks (p. 455).

It is hoped that the trend of the evolution of systematic petrography during the earlier portion of the microscopical era has been fairly indicated in the preceding pages. The tendency, most natural under the circumstances, was to overestimate the systematic importance of some of the discoveries made through the microscope, and to slight other, more fundamental, properties or relations of rocks. Many new rock names were proposed and usage became fixed and extended in directions where it had never been well grounded. Protests against the tendency of the times were numerous, and especially from the geologist's standpoint. Many of these protests were of little influence, because based upon imperfect appreciation of the situation; others were far too conservative in spirit.

J. D. Dana, 1878.—As an example of the conservative geologist's view at this time may be cited the discussion of petrographic system by J. D. Dana in an article published in the *American Journal of Science* in 1878 under the title "On some Points in Lithology."[1] This article refers to the *Mikroskopische Physiographie* of Rosenbusch, and to other recent works, and may be taken as expressing the author's view of petrography at the stage of its development just reviewed.

Lithology, according to Dana, is charged with the descrip-

[1] *Amer. Jour. Sci.*, 3d ser., Vol. XVI, p. 335, 1878.

tion and naming of rocks. It has "to note down their distinctions in such a manner as shall best contribute to the objects of geology." "From granite down they [rocks] are with very few exceptions mixtures of minerals, as much so as the mud of a mud bank." "Strongly drawn lines exist nowhere." "Rocks are therefore of different *kinds*, not of *different species;* and only those mixtures are to be regarded as *distinct kinds* of rocks which have a sufficiently wide distribution to make a distinct name important to the geologist."

Dana discusses the bases of classification adopted by petrographers of this time, such as age, structure, and contents in certain minerals, and objects to most of them as trivial or wrongly used. He then proposes an arrangement of the "Crystalline rocks, exclusive of the calcareous and quartzose kinds," under the following groups :

I. Mica and potash feldspar series — Granite, gneiss, mica schist, trachyte, etc.

II. Mica and soda-lime feldspar series — Kersantite, kinzigite, ditroite, phonolite, etc.

III. Hornblende and potash feldspar series — Syenite, hornblende-schist, foyaite, etc.

IV. Hornblende and soda-lime feldspar series — Diorite, andesite, euphotide, etc.

V. Pyroxene and potash feldspar series — Amphigenite.

VI. Pyroxene and soda-lime feldspar series — Augite-andesite, norite, dolerite, etc.

VII. Pyroxene, garnet, epidote, or chrysolite rocks, containing little or no feldspar, lherzolite, dunite, garnetite, etc.

VIII. Hydromagnesian and aluminous rocks. Chloritic, talcose, and other schists, serpentine, etc.

While Dana does not refer in this article to the broader grouping of rocks, it appears, from various editions of his *Manual of Geology*, that he uses mode of origin to distinguish the three great classes — Igneous, Sedimentary, and Metamorphic — in discussing that question ; but, in arranging rocks for description, he abandons that principle, and makes another division as more convenient. Convenience of presentation, and not expression of natural relations, is really the object of Dana's arrangement. It

is, therefore, not strictly a petrographic system. In the second edition of the *Manual* (1874), igneous and metamorphic groups were separated in description; but, probably for the reason that such a course involved the splitting up of granitic, syenitic, and other types supposed to be metamorphic in part and eruptive in part, Dana had, in 1878, evidently adopted the arrangement found even in the last edition of the *Manual* (1895), whereby *crystalline* and *fragmental* were opposed to each other, as by Zirkel in 1866.

Dana was never able to adopt the modern petrographic systems, founded so largely upon erroneous assumptions, like the age distinction among igneous rocks, or upon genetic views with which he was not in accord, and contented himself with an arrangement of convenience. The main features of this order of description appearing in the *Manual of Geology*, 1895, are seen from the four primary groups under which all rocks were treated:

1. Limestones, not crystalline.
2. Crystalline limestones.
3. Fragmental rocks, not calcareous.
4. Crystalline rocks.

The crystalline rocks were described under five heads:

I. Siliceous rocks, or those consisting mainly of silica.
II. Rocks having alkali-bearing minerals as chief constituents.
III. Saussurite rocks.
IV. Rocks without feldspar.
V. Hydrous magnesian and aluminous rocks.

The second group was divided nearly as in the proposition of 1878, above cited. This resulted in bringing together such unlike things as granite, greisen, minette, slate, agalmatolite, porcelain jasper, obsidian, etc., in the "Potash Feldspar and Mica Series."

Karl A. Lossen.—Among other protests raised by geologists against the tendency to treat rocks fom the microscopist's alleged narrow standpoint, one of the more philosophical discussions had an acknowledged effect making it worthy of notice; namely, that by Karl A. Lossen, himself a petrographer of dis-

tinction, yet in first degree a geologist, prominent upon the Prussian geological survey.

The views held by Lossen were repeatedly expressed, and were summed up in a discussion of principles entitled *Über die Anforderungen der Geologie an die petrographische Systematik*.[1] The "demands" here forcibly expressed are based upon the idea that, *because the rock is a geological body, the geological relations of rocks must be recognized as petrographical relations.* Of all the geological relations of rocks Lossen selected that which seemed to him the most important, and claimed that that principle should be used as the primary factor in petrographic classification. The relation of rock masses to the earth sphere appealed to Lossen as all important, and on that criterion all rocks were considered as *stratified* or *massive*. Stratified rocks were defined as those accumulated upon the earth's surface under the controlling influence of gravity, causing them to assume in some degree the form of concentric strata normal to the radius of the earth. The material of massive or eruptive rocks, on the other hand, was viewed as having been forced from the depths directly against the influence of gravity, consolidating like a casting, under the control of surrounding conditions. Surface lavas, spreading out in sheets, while controlled largely by gravity in their formal relations, were referred by Lossen to massive rocks, because possessing the resemblance to a casting from one pouring, and not as built up by successive additions, layer upon layer. It will be seen that the molten condition of magmas was actually a leading factor in Lossen's idea, although the avowed intention in using *eruptive* as an alternative for *massive* was to express the force opposed to gravity, and not the molten state which rendered them susceptible to that force.

Lavas are not the only rock masses difficult of consistent treatment under Lossen's principle. Pyroclastic tuffs were considered as illustrating the fact that "das Ineinandergehen zum Wesen der Gesteinsnatur gehört." Lossen confessed, further, that rocks of the first crust of the earth, according to the nebu-

[1] *Jahrbuch der k. pr. geol.* Landesanstalt, 1883, p. 486.

lar hypothesis, would necessarily be separated from his eruptive class, but he considered this point immaterial because he doubted whether any such rocks were known. Metamorphic rocks are of such diverse origin and present such difficulties to the systematist that Lossen considered it inadvisable to treat them as a distinct class.

In this discussion by Lossen, as in the majority of those emanating from geologists, no appropriate distinction is made between the rock mass as a formal unit and the material within it, the rock proper. The primary division of Lossen is one of rock masses, not of rocks. The consideration of the form and position of these masses with regard to the controlling influence of gravity or the opposing eruptive force, leads to only one of many ways in which the geologist must classify rock bodies. Other elemental subdivisions of the same bodies are necessary. The geologist is, indeed, obliged to make and discuss all such fundamental distinctions. The petrographer, on the other hand, should not only be at liberty to select, but, in order to secure logical excellence for his system, *must* choose, as his primary principle, that one most closely connected with the factors which he has adopted for use in the further construction of the systematic arrangement of rocks. It is clear that all igneous rocks, those produced by the consolidation of molten magmas, possess, from this origin, material properties most useful in their detailed classification. If arrangement by a certain characteristic due to this origin is desired, it matters not where the rocks occur in the earth. They may belong to the primeval crust, or form injected masses of whatever size, shape, or attitude, or appear on the surface in lava streams. If it was mode of origin, not formal relations to the earth, which gave igneous rocks the common characters used in their systematic arrangement, then mode of origin is logically the principle to be used by the petrographer to bring them into one grand division.

H. Rosenbusch, 1887.—As has been mentioned, the force of Lossen's claim, as made in earlier publications, was admitted by H. Rosenbusch, in the first edition of his *Mikroskopische Physio-*

graphie der massigen Gesteine, "massig" being used in the sense explained by Lossen, and not in that of textural condition. In the second edition of this widely-used handbook, which appeared in 1887, Rosenbusch repeated his approval of Lossen's proposition, and in the revision of his petrographic system further emphasized geological occurrence as a factor of prime classificatory value for eruptive rocks. The great changes in system found in this volume make it practically a new work, but a detailed statement of its scheme seems unnecessary since all petrographers may be assumed to be familiar with it.

In the decade since the appearance of the first edition, Rosenbusch effected a complete change of systematic base in some important respects, the reasons for which are given in the preface. He now considers rocks as the documents in which the history of the earth is written, and petrography, as the science which teaches us how to decipher those documents, becomes to him *a historical and not a descriptive science*. To quote his declaration:

> The recognition of these relations made the new edition of this book practically a new work. Its end will have been achieved if I have succeeded in procuring for this fundamental conception a general acceptance, and have demonstrated that rock structure affords the safest and most productive means for the construction of a natural system of rocks.[1]

A natural system of rocks must therefore be historical, *i. e.*, genetic. Plainly the logical analysis of the broad science of rocks presented by Naumann was either forgotten or ignored by Rosenbusch.

With this statement of controlling principles in mind, one involuntarily recalls that in the first edition of the *Mikroskopische Physiographie* the rocks to be discussed were designated *massive* in preference to *eruptive* because the former term was considered free from expression of any genetic idea. In this second edition, while advocating the genetic basis of classifica-

[1] "Die Erkenntniss dieses Verhältnisses machte die neue Auflage dieses Buches zu einer Neubearbeitung. Der Zweck derselben wird erreicht sein, wenn es mir gelungen ist, dieser Grundanschauung eine allgemeinere Anerkennung zu verschaffen und darzuthun, dass die Gesteinsstructur das sicherste und ausgiebigste Mittel zum Aufbau eines natürlichen Systems der Gesteine an die Hand giebt."

tion as all important, Rosenbusch retains the group term *massive*, yet in both works it is clearly the igneous origin which is first in mind and which is recognized as of prime importance in producing rock structure, chosen as the leading factor in constructing the new system.

After having stated his belief that rock structure is the best basis of classification of "massive rocks" Rosenbusch proposed to divide them into three groups: (1) Deep-seated rocks ("Tiefengesteine"), (2) Dike rocks ("Ganggesteine"), and (3) Effusive rocks ("Ergussgesteine"). The critic is obliged to point out that this proposition is inconsequent, for not only is structure not expressed in the terms chosen, but another distinct factor is expressed, namely, mode of occurrence. The further development of Rosenbusch's scheme makes it clear that he did not intend to emphasize the actual facts of geological occurrence, plainly as he stated them, but rather to express in this way his conception of the genesis of structure. Recognizing that different structures result from the consolidation of a given magma according to the attendant conditions, Rosenbusch selected the geological factor appearing to him of greatest influence among many conditions and made that the expressed basis of structural classification. Since simplicity and logical directness are surely of utmost importance in systematic constructions the unnecessary indirectness of this proposition may be designated a fatal weakness. Furthermore, the geologist is warranted in objecting to it because the expressed division of igneous rocks is one which he has used in the past and must use in the future, in its literal and appropriate sense, quite apart from the idea hidden in the terms of Rosenbusch's system.

To the above noted criticisms of Rosenbusch's first application of structure in classification must be added another, based upon the fact that the division of *Dike rocks* was not in reality provided for rocks occurring in dikes, but for a group of rocks for which Rosenbusch assumed a certain genesis. An hypothesis of magmatic differentiation and assumptions of limited occurrence and of characteristic structure are all involved in the dis-

crimination of the group named "Dike rocks." In this light this group is certainly not co-ordinate with the other two of the same rank as defined.

In the subdivision of the three classes of "Massive rocks" Rosenbusch applied mineral composition as a factor, producing Families. The quantitative composition, either chemical or mineral, received no expression, so that, for example, anorthosite and the most highly pyroxenic gabbro or norite are found together in the gabbro family. Moreover in the porphyritic Dike rocks only the phenocrysts are considered in determining the systematic position of a given rock. Thus a porphyry having the chemical composition of a granite is referred to syenite-porphyry in case its excess of silica chances to be confined to the groundmass, while had quartz phenocrysts been present it would have been called granite-porphyry. In the Effusive rocks, Rosenbusch hesitates to apply the same rule consistently. The families of these rocks are defined in very general terms as the "equivalents" of certain granular rocks and described as containing certain phenocrysts in a groundmass of variable appearance.

As in the earlier system, all feldspar-free rocks of the deep-seated class are united as Peridotites. The peculiar character of the Dike rocks as a division not co-ordinate or co-extensive in range with the Deep-seated or Effusive rocks appears in the fact that mineralogical groups corresponding to the granites, syenites, and diorites, only, are recognized.

Geological age is acknowledged by Rosenbusch to have been assigned a higher value in classification than belongs to it, but it is retained, in the Effusive class, and the use of duplicate terms perpetuated.

H. Rosenbusch, 1896.—The third edition of the "*Mikroskopische Physiographie der massigen Gesteine*," issued in 1896, contains no essentially new systematic features. The principles above set forth are reaffirmed, and, save for the elaborated discussions of magmatic differentiation, which show more plainly than in the preceding edition the strong influence of hypo-

thetical considerations in giving form to this system, there is little of note to comment upon in this place. In discussing the essential characters of the three groups of Dike rocks, Rosenbusch brings out more forcibly than before the genetic idea really lying at the base of the distinction of the Dike rock class. In connection with the discussion of the Dike rocks it is suggested that a further class may be necessary to include the intrusive rocks of sheets and laccoliths which seem to him to possess distinctive structures.

That the system of Rosenbusch does not result in a consistent and logical classification of igneous rocks is abundantly illustrated by numerous instances, many of them freely acknowledged by the author. The family of the diabase rocks furnishes one of the most notable cases. In 1887 these rocks were classified with the deep-seated rocks, although many of them were known to be effusive; in 1896 the same rocks are placed with the effusives, with the statement that many are intrusive. Placed in the effusive class, they are acknowledged to be partly of older and partly of younger age, but no age distinction is thought to be practicable.

Justus Roth, 1883.—Shortly before Rosenbusch issued the second edition of his *Physiographie*, there appeared a complete systematic discussion of rocks by Justus Roth, in the second volume of his *General and Chemical Geology*.[1] Petrography is defined by Roth as the science of the mode of origin, constitution, and alteration of rocks; *i. e.*, the petrology of many English and American writers. In introducing the systematic descriptive part of the subject, Roth remarks: "The difficulty in constructing a system of rocks is completely expressed in the term *aggregate*, and thereby all recourse to genera and species is prohibited."[2] From the nature of rocks and the conditions of

[1] *Allgemeine und chemische Geologie;* Zweiter Band, "Petrographie" (Berlin, 1883–1885), pp. X + 695.

[2] "Die Schwierigkeit der Systematik der Gesteine ist durch die Bezeichnung Aggregat vollständig ausgedrückt und damit alle Anlehnung an Gattungen und Species ausgeschlossen," *loc. cit.*, p. 41.

their origin, he thinks that every system must so largely represent individual opinion that probably no one system can ever receive universal recognition.

The systematic arrangement of Roth is, in its general outline, as follows:

A. Rocks composed essentially of minerals.
  I. Plutonic (consolidation products of molten magmas). Free from fossils, composed of minerals or substance chemically like a mineral aggregate.
    1. Eruptive. (Breaking through other rocks.)
      a. Pre-Tertiary.
      b. Post-Cretaceous.
        Appendices to *a* and *b* contain rocks produced by weathering. Tuffs.
    2. Crystalline schists.
      Appendix-Weathering products.
  II. Neptunic.
    1. Partly fossiliferous; composed of minerals and of the products of the decay, decomposition, and attrition of minerals.
      a. Precipitates from solution.
      b. Deposits from suspension.
    2. Clastic, composed of rock fragments.
B. Rocks composed essentially of organic remains.
C. Products of contact metamorphism.

It will be observed that the ancient crystalline schists are regarded as the primary crust of consolidation of the earth.

The geological factors of origin, relations, or age, are variously applied in the construction of this scheme, and in constitution the distinction between mineral and rock particles is made. All Plutonic rocks are regarded as consisting essentially of silica or *silicates*, excepting that in the crystalline schists *carbonates* appear. The silica free minerals—apatite, magnetite, ilmenite, etc., are treated as accessory constituents. This exclusion of the latter group of minerals from a position of systematic importance is not discussed by Roth, but its evident result is that in certain rocks, *e. g.*, those rich in magnetite, the components do not have their natural and logical weight in classification.

Of the pre-Tertiary eruptive rocks, Roth makes, for convenience, three divisions:

I. Orthoclase rocks.
II. Plagioclase rocks.
III. Peridotites.

The first two of these groups should, logically, have been united systematically in the division of Feldspathic rocks, including all with appreciable content in feldspar, since the Peridotites are defined as free, or nearly free, from feldspar. The question of recognizing the quantitative relations of mineral constituents is not mentioned by Roth.

The silicate minerals are applied by Roth for the subdivision of the three main groups in the usual way, and by means of *structure* the granular, porphyritic, and glassy varieties are distinguished.

In the detailed treatment of Eruptive rocks, as in the arrangement of Crystalline schists, the Neptunic rocks and the Classes B and C, mentioned above, Roth's order of presentation and discussion can hardly be said to be systematic. It is an arrangement for convenience of description, not based upon the logical application of principles; and it is, therefore, not desirable to devote more space to its analysis in this review.

E. Kalkowsky, 1886.— A condensed text-book on rocks was published by E. Kalkowsky, in 1886, with the title *Elemente der Lithologie.*[1] For the primary division of rocks the author formulates an original criterion, and proposes two great classes:

I. "Anogene"—of which the material came to the place of rock formation from *below.*

II. "Katogene"—of which the material was derived from *above.*

These correspond closely to the eruptive and sedimentary divisions of other authors.

For the classification of the "Anogene" rocks Kalkowsky applies the following factors: (1) Chemical composition as represented in mineral composition; (2) the usual age distinction; (3) structure. He rejects genetic distinctions as unsuit-

[1] Heidelberg, 1886, pp. 316.

able. In detail Kalkowsky's scheme is similar in its results to that of Zirkel, but, as he does not define his smaller rock divisions, a further discussion of his arrangement seems unnecessary. The definitions are omitted, according to the author, because the student must learn to know the rocks by the study of named hand specimens and will, therefore, find out what they are without definitions.

J. J. Harris Teall, 1886, 1888.—The most extensive treatise on rocks thus far published in England is the descriptive work *British Petrography*, by J. J. Harris Teall, issued almost simultaneously with the second edition of Rosenbusch's *Massige Gesteine*. This work lays no claim to being a systematic petrography, and describes almost exclusively the igneous class; but from its scope a discussion of principles of rock classification was necessary, as explanatory of the arrangement actually used. Teall considers rocks so complex and indefinite in character that in the existing state of knowledge no true systematic arrangement is possible. His order of presentation is, in fact, one of convenience, and does not express his own views of the most natural basis of classification.

In discussion of principles, Teall points out that chemical composition, as the constant and primary character of igneous rocks, is the natural basis of classification and in accordance with the Bunsen law of two magmas. He, however, does not work out any new proposition to use chemical composition. The arrangement under which rocks are described is a mixture of the methods of Rosenbusch and Michel-Lévy. All igneous rocks are placed in seven groups, as follows:

A. Rocks composed of the ferro-magnesian minerals: olivine, enstatite, augite, hornblende, and biotite. Feldspar absent; or, if present, occurring only as an accessory constituent.

B. Rocks in which plagioclase is the dominating feldspathic constituent. Nepheline and leucite absent. Orthoclase is frequently present.

C. Rocks in which orthoclase is abundant. Plagioclase usually present. Nepheline and leucite absent.

D. Rocks containing nepheline or leucite; sometimes nepheline and leucite.

E. Rocks not included in any of the preceding groups.

F. Vitreous rocks.

G. Fragmental volcanic rocks.

It will be seen that this grouping is mainly mineralogical and does not express the quantitative element in any logical way. It practically recognizes the entrance of feldspar, in any amount above that of the undefined "accessory" rôle, as creating a large group of *feldspathic rocks.* The subdivision of these groups is first on some further mineral distinction and after that occurrence and texture enter combined into the system by distinguishing rocks of *granitic* from those of *trachytic* texture, using these terms in the sense of Fouqué and Michel-Lévy, and conceiving that the result is practically to separate *plutonic* or deep-seated from *volcanic* or effusive rocks. Age is not introduced as a factor.

Within the last twenty years several attempts have been made to apply, *in extenso*, the chemical composition of rocks for their classification. These attempts have been prompted by various motives. Some appear to have no really practical object, viewed from the petrographer's standpoint; others are connected with hypotheses of magmatic differentiation; and still others have been inspired by a realization of the complexity of the problem of a rational arrangement of rocks on the basis of their numerous and highly variable mineral constituents. It appears to the writer, however, that it may be fairly said of all these attempts that they are either not classifications of *rocks*, or that they are not actually *chemical* classifications.

Franz Schröckenstein, 1886, 1897.—Two peculiar attempts by Franz Schröckenstein, an Austrian writer, to discuss the chemical composition of silicate rocks, irrespective of their origin, and upon that basis to classify them, are mentioned here only for the sake of completeness, as these attempts have no direct bearing upon a logical system of rocks. The writer has seen only the more recent of the essays in question,[1] depending for the

[1] "Silicat-Gesteine und Meteorite," *Petrographisch-chemische Studie auf Grundlage des neuesten Standes der Wissenschaft bearbeitet.* Prag, 1897.

earlier one[1] upon the summary given by F. Loewinson-Lessing.[2]

Schröckenstein's view of igneous rocks will, on account of its fantastic imaginings, impress many a reader as belonging rather to the eighteenth, or a still earlier, century, than to the close of the nineteenth ; and, although his propositions are of no consequence to petrography, the fact that they have been put forth at all, in the very last decade of the period in review, has a certain melancholy interest.

Schröckenstein considers the original crust of the earth to have been a *silicate of alumina*, probably with excess of silica. This simple primary magma is conceived to have been first rendered impure by meteoric showers, introducing lime, magnesia, and iron. At a later period the alkalies and water were precipitated from the atmosphere. The alkalies are considered as of very subordinate (" nebensachlich ") importance and the chemical problem of rocks, as the author views it, is to compare the relative amounts of the original alumina silicate and the meteoric impurities. That is to say, *the author proposes classes according to the degree of adulteration of the original magma and orders according to the character of the adulterant.*

The method followed by Schröckenstein in comparing analyses of silicate rocks appears to be somewhat as follows :

First, magnetite is calculated out, as an *extraneous substance*, whenever the analysis is sufficiently modern, through determinations of both ferric and ferrous oxides, to give a basis for such calculation. When the analysis is inadequate and the iron is lumped under one or the other oxide, the result is accepted by the author and Fe_2O_3 is supposed to replace alumina or FeO is added to MgO and CaO. Not until magnetite is deducted does Schröckenstein consider that the real rock is under discussion. Inasmuch as he states that after deducting magnetite there is either no iron left or but one oxide appears, it is evident that the

[1] Ausflüge auf das Feld der Geologie," *Geologisch-chemische Studie der Silicatgesteine*, II Auflage, Wien, 1886.

[2] " Studien ueber die Eruptivgesteine," *Compte-Rendu, VII Cong. Géol. Internat.*, 1899, p. 196.

maximum possible amount of magnetite is deducted. The remainder is then calculated to 100. The analyses are not given in their original form.

The systematic plan of Schröckenstein consists, in his later publication, in establishing five classes of silicate rocks, according to the relations of Al_2O_3 to RO ($=CaO + MgO + FeO$) as shown by the *percentages* of the calculated remainder after deducting magnetite.

$$\text{I. } \frac{RO}{Al_2O_3} < \frac{1}{4}; \quad \text{II. } \frac{RO}{Al_2O_3} < \frac{1}{2} > \frac{1}{4}; \quad \text{III. } \frac{RO}{Al_2O_3} < \frac{3}{4} > \frac{1}{2};$$

$$\text{IV. } \frac{RO}{Al_2O_3} < \frac{1}{1} > \frac{3}{4}; \quad \text{V. } \frac{RO}{Al_2O_3} > \frac{1}{1}.$$

Two orders appear under each class according as lime or magnesia dominates.

Although Schröckenstein professes to use the latest information, as stated in the title of his recent publication, his results are based upon the discussion of 340 analyses, many of them old, while on the other hand no single one of the hundreds of analyses made in the laboratory of the United States Geological Survey, within the past twenty years, is utilized. Hundreds of European analyses of recent date are also ignored.

It seems unnecessary to give any further details concerning Schröckenstein's propositions. He is not actually treating rocks and his superficial considerations of chemical composition can have no bearing upon true petrographic system.

H. O. Lang, 1891.—An attempted arrangement of igneous rocks on a chemical basis by H. O. Lang,[1] in 1891, is founded on the idea that since the feldspars are the most important constituents of eruptive rocks, an appropriate and practical chemical basis of classification may be found in the relations of the bases potash, soda, and lime, the distinctive elements of the various species of feldspar. In one case Lang used the percentage

[1] "Versuch einer Ordnung der Eruptivgesteine nach ihrem chemischen Bestande," *Tscher. Min. Pet. Mitth.*, XII, 1891, p. 199.

"Das Mengenverhältniss von Calcium, Natrium, und Kalium als Vergleichungspunkt und Ordnungsmittel der Eruptivgesteine," *Bull. Soc. Belge de Géol.*, 1891, V, p. 123.

amounts of the oxides found by analysis, and in the other the amounts of the elements potassium, sodium, and calcium. Here again is the situation that only a part of some rocks is actually under discussion, and the result can be of no real value to petrography.

F. Loewinson-Lessing, 1890, 1897. In 1890 an attempt at a chemical classification of igneous rocks was made by F. Loewinson-Lessing,[1] based upon the quantitative relations of silica to the various oxides of the bases, grouped under R_2O, RO, and R_2O_3, as shown in *percentages* by bulk analysis. By means of empyrical formulæ the author thought to find a way of expressing regular relationships supposed to exist between the silica contents and the various oxide groups. Rocks exhibiting the following simple relationships were designated *types*, I to V being the principal ones, and VI to IX intermediate:

Acid Rocks:

$$\text{I. } SiO_2 = 2(R_2O + RO) + R_2O_3 + Q\ .$$

$$\text{VI. } SiO_2 = \frac{3}{2}(R_2O + RO) + R_2O_3 + Q\ .$$

Neutral Rocks:

$$\text{II. } SiO_2 = 2(R_2O + RO) + R_2O_3 \left(\text{II} = \frac{\text{I} + \text{IV}}{2}\right) .$$

$$\text{VII. } SiO_2 = \frac{3}{2}(R_2O + RO) + R_2O_3\ .$$

Basic Rocks:

$$\text{III. } SiO_2 = R_2O + RO + R_2O_3 \left(\text{III} = \frac{\text{II} + \text{IV}}{2}\right) .$$

$$\text{VIII. } SiO_2 = R_2O + RO + \frac{1}{2} R_2O_3 \left(\text{VIII} = \frac{\text{III} + \text{IV}}{2}\right) .$$

Ultra Basic Rocks:

$$\text{IV. } SiO_2 = \text{or} < RO\ .$$

$$\text{IX. } SiO_2 = \frac{1}{2} RO\ .$$

$$\text{V. } SiO_2 = O\ .$$

Since percentages instead of molecular ratios were used, the simple relations here adopted have no real significance as expressing a regular connection between chemical and mineral composition. This fault was perceived by the author and cor-

[1] "Étude sur la composition chimique des roches éruptives," *Bull. Soc. Belge de Géol.*, 1890, IV, Mem., p. 221.

rected in the publication to be discussed below. These so-called types were assumed by Loewinson-Lessing to correspond more or less closely to certain commonly known rock groups.

The more elaborate discussion of the chemical relationships of igneous rocks by Loewinson-Lessing, presented to the International Geological Congress at St. Petersburg, in 1897, and published two years later in the *Compte-Rendu*, deserves somewhat fuller consideration.[1] A brief statement of the author's point of view is desirable before explaining the system proposed.

In reviewing the applicability of various factors in producing a rational system, Loewinson-Lessing asserts that the mineral composition of a rock is a function of its chemical composition. The exceptions to this rule admitted by him are of little importance. Then follows the further statement that the principle or characteristic of mineral composition as a basis of classification is faulty and unsatisfactory because it does not show the relative abundance of the minerals in the various rocks. That is, however, as it appears to the writer, not the fault of the *principle*, but of the manner in which it has been applied in existing systems. If mineral composition is a function of the chemical composition, it is just as capable of expressing the constitutional relations of rocks as the latter, if properly used. The real objection to its application in the quantitative way, necessary to this expression, is simply one of practicability. The problem is too complex.

As for his own system, Loewinson-Lessing starts from the idea that eruptive rocks may be considered as *silicate rocks* and classified as such. Whatever the facts as to predominance of silicates in these rocks may be, it seems to the writer that this conception is not complete as to its basis of fact, and is thus inadequate to serve as a means of classification. Further fundamental propositions enunciated by the author are that: (1) silicate rocks should be classified by the same artificial means as the silicates themselves; (2) while rocks are not stoichiometric

[1] F. LOEWINSON-LESSING, "Studien über die Eruptivgesteine," *Compte-Rendu de la VII session du Congrès Géologique International, Russie*, 1897, pp. 193–467.

compounds, they are not accidental mixtures; (3) one must consider the relative amounts of *all* oxides of bases to each other and to silica; (4) as silica is the dominant constituent it is proper to take it as the basis for the primary classification; (5) the next factor to be applied must be the contents in the three oxide groups, alkalies, alkaline earths, and the sesquioxides; (6) various single oxides may be used for further subdivisions. From this statement it might be supposed that a classification created by the successive use of the chemical factors named was to be set up by Loewinson-Lessing, and such an arrangement of magmas would have claim to being a chemical classification. But the author does not do that, as we shall see.

The actual system proposed by Loewinson-Lessing is to use the silica contents for the formation of four general groups: (1) Acid rocks; (2) Neutral rocks; (3) Basic rocks; (4) Ultrabasic rocks.

The second division is obtained by taking a certain number of analyses representing known rock families (established on the unsatisfactory basis of mineral composition) and determining the *mean* of these analyses, which is then set up as the composition of a rock *type*, and its formula and coefficient of acidity are ascertained.

It is clear that the grist of this mill depends entirely upon what is put into the hopper. It is not a chemical classification but a chemical *characterization* of mineralogical rock groups arbitrarily selected by the author. It will, of course, be possible to secure means corresponding to any formula desired as a type, and the rocks thus having typical position could be adopted as centerpoints of groups or families. For the ordinary range of rocks these types would often coincide with recognized rocks, assigned certain names in existing systems, and these names might then be given by redefinition to the families thus indicated. But what would be the purpose of such a scheme? It could not express the existing relations between the mineral composition of the rock and the chemical constitution of the magma.

A. Osann, 1900, 1901.— A further attempt to utilize chemical composition as a factor in the classification of igneous rocks was made by A. Osann in the closing year of the century. Under the title "Versuch einer chemischen classification der Eruptivgesteine"[1] Osann essays to use chemical composition as a supplement to mineral and textural characters, by establishing various chemical types within rock families formed upon the Rosenbusch system. The author accepts the classes of deep-seated, dike and effusive rocks, in the Rosenbusch sense, and the vaguely defined families established upon mineral composition. Realizing that by this latter factor, as currently applied, the relative abundance of the minerals is not sufficiently taken into account, Osann attempts to bring out quantitative relations, within the families, by establishing certain types upon the basis of chemical composition.[2]

It is clear that if the quantitative element was not sufficiently expressed in forming the families discussed by Osann, he fails to remedy the defect. A logical subdivision of the families on a chemical basis would principally serve to point out the defects in this respect, and would really weaken rather than strengthen the system as a whole.

But the "types" set up by Osann are in no sense systematic divisions of the families. The "type" of this author is simply a chosen well-analyzed rock, differing in chemical composition from other rocks within its family, according to the adopted method of comparison. To a type thus established are referred other rocks of nearly identical chemical characters. But the types bear no definite relation to each other or to the family.

[1] *Tschermak*'s *Min. und petr. Mittheilungen*, Bd. XIX, 1900, pp. 351–469, and Bd. XX, 1901, pp. 399–558.

[2] The author's standpoint may be sufficiently understood from the following statement: "Der Hauptmissstand der mineralogisch-structurellen Classification liegt darin, dass dem relativen Mengenverhältniss der wesentlichen Gemengtheile zu wenig Bedeutung zuerkannt wird, und es wird gerade die Hauptaufgabe der chemischen sein, in dieser Richtung ergänzend und vertiefend zu wirken." "So kann es sich bei dem hier unternommenen Versuch ebenfalls nur um ein künstliches System handeln, welches in erster Linie dazu bestimmt ist, das mineralogisch-structurelle zu ergänzen." *Ibid*, Bd. XIX, pp. 351–352.

They merely serve to show the chemical range found within the families so far as Osann's examination extends.

From the above statement it would appear that Osann has not, in reality, proposed a chemical classification in the systematic sense, and hence it is not desirable to enter further into the analysis of this elaborate discussion of the chemical varieties represented within the families of the Rosenbusch system.

This discussion of petrographic systems proposed during the nineteenth century will close with a review of three attempts to bring all known rocks into orderly arrangement. Not that the authors think to have formulated natural or logical systems, for that is expressly disclaimed by them. Yet in presenting these comprehensive arrangements of rocks, according to the light of the last decade of the century, these authors define and illustrate in a most effective way the present condition of systematic petrography.

Ferdinand Zirkel, 1893, 1894.—The second edition of Zirkel's *Lehrbuch der Petrographie* is the most comprehensive and complete description of all known rocks ever published, and it therefore represents the present status of the systematic science as a whole, better than any other work, and hence deserves careful consideration. But the fact staring the student in the face is that systematic petrography is still very largely an arrangement for convenience of description, and is not, in its entirety, a logical expression of relationships. Within the division of igneous rocks there is at least some attempt at system, but the other rocks confessedly defy logical treatment by any method as yet proposed.

The primary division of all rocks is on general geological grounds into four groups:

I. Igneous rocks—"Massige, eruptive Erstarrungsgesteine."
II. Crystalline schists.
III. Sedimentary crystalline rocks (not clastic.)
IV. Clastic rocks.

This division is clearly based on geological considerations,

and is chosen in place of the primary arrangement of the first edition because, as Zirkel points out, of inconsistencies and unnatural associations which resulted, some of which have been mentioned in this review. Contact metamorphic rocks are treated in connection with the igneous rocks which produced them. Fragmental igneous rocks are placed with the clastics.

In the systematic classification of igneous rocks Zirkel uses the bases of arrangement in the following order: (1) mineral composition; (2) structure; (3) age. The availability of chemical composition, alone, or in expressed combination with mineral constitution, is not discussed. The method of applying mineral composition for the classification of igneous rocks is that commonly used. Concerning this Zirkel remarks:

> In a mineralogical arrangement of massive rocks the following considerations are at present determinative: In the great majority of these rocks feldspars and other silicates resembling feldspars (such as nephelite, leucite, melilite) play the chief rôle, and therefore it is most natural to base the classification of such rocks upon the nature of these minerals, in accordance with existing nomenclature.[1]

This procedure results in placing *feldspar- or feldspathoid-bearing* rocks in one large group opposed to *feldspar-free* rocks. Whatever the facts may be as to the relative quantitative importance of different minerals in igneous rocks, it is clearly arbitrary to concede to any mineral the "principal rôle" where it is far subordinate to others. The result is a qualitative expression of mineral composition, bringing chemically unlike rocks together in many divisions.

In the descriptive portion of the *Lehrbuch*, igneous rocks are grouped under seven heads:

I. Rocks with alkali feldspar and quartz or excess of silica.

II. Rocks with alkali feldspar, without quartz or excess of silica, without nephelite or leucite.

[1] Für die mineralogische Gruppirung der Massengesteine sind zur Zeit folgende Erwägungen maassgebend: In der weitaus allergrössten Mehrzahl derselben spielen Feldspathe und andere feldspathähnliche Silicate (wie Nephelin, Leucit, Melilith) eine Hauptrolle und so scheint es am natürlichsten, die Classification der hierher gehörigen Gesteine auf die Natur dieser Mineralien zu begründen, was zugleich der bestehenden Nomenclatur entspricht. — *Petrographie*, Band I, p. 832.

III. Rocks with alkali feldspar, without quartz or excess of silica, with nephelite (haüynite) or leucite.

IV. Rocks with lime-soda feldspar, without nephelite or leucite.

V. Rocks with lime-soda feldspar and nephelite or leucite.

VI. Rocks without true feldspars, but with nephelite, leucite, or melilite.

VII. Rocks without either feldspars or feldspathoid.

Structure and geological age are applied by Zirkel under each of the mineralogical groups, as follows :

Granular rocks.
  (No distinctions by age.)
Porphyritic and glassy rocks.
  Pre-Tertiary.
  Tertiary and recent.

The structural distinction is clearly in fact between (1) granular and (2) non-granular, the range in structure within the second division being by no means covered by the two terms porphyritic and glassy.

The use of age as a factor in classification of "porphyritic and glassy rocks" while it is not applied to the granular rocks is apparently more a recognition of the usage of the time, by which a duplicate set of terms has been provided for effusive rocks, than of any definite principle. The task of reconstructing the nomenclature of the science is still one from which the systematic petrographer shrinks.

The group of the *crystalline schists* established by Zirkel is not founded upon definitely stated principles, and is therefore not a systematic group. It is defined by enumeration of things belonging in it or excluded from it, and must be treated as a convenient expedient for purposes of rock description. But although this is true the crystalline schist group of Zirkel is no more unsystematic than the assemblages of other petrographers given the same name. It is then germane to the present discussion to state the actual course adopted in the *Lehrbuch*.

Zirkel includes in his group of the crystalline schists, and as its most important element, the pre-sedimentary gneisses, schists, etc., which cannot be inferred from their attitude to other rocks to be of igneous origin. Included with these are all rocks of the

same texture and composition demonstrably derived from sediments or occurring intercalated in the sedimentary series but not clearly of igneous origin. Excluded from the group under discussion are the primarily banded igneous rocks and the metamorphic derivatives of igneous rocks whenever that origin can be established, and whatever the process of change may have been. In other words the group includes the rocks below the oldest known sediments so far as they are not visibly eruptive or igneous and all later rocks of the same characters derived from sediments or of unknown origin.

This group then has nothing in texture or composition to distinguish it. Neither of the elements of the name has any restrictive significance. The group is geologically homogeneous only in case the schists of unknown origin are actually derived from sediments. If, as many suppose, a large proportion of the Archean gneisses, etc., represent igneous masses, metamorphosed or not, the group is not only heterogeneous from the genetic standpoint but causes the separation of identical things.

In the subdivision of the crystalline schists mineral composition is applied, the predominant constituent causing the reference of a rock to a certain group. The terms gneiss and schist are not defined.

The group of *crystalline, or non-clastic sedimentary rocks*, is heterogeneous in constitution as is apparent from a partial list of the rocks referred to it : ice, cryolite, limestone, opal, quartzite, porphyroid, iron ores, coals, diatomaceous earth. That such a group lacks the unity required in a systematic division, and that its descriptive name by no means covers the case, is apparent at once. It is confessedly a grouping for convenience only, and embraces, in fact, the remaining rocks after the other three have been established.

H. Rosenbusch, 1898.— A comprehensive discussion of rocks was issued in 1898, by H. Rosenbusch, entitled, *Die Elemente der Gesteinslehre.*[1] Although much less detailed than the *Lehrbuch* of Zirkel, this work is of much interest as expressing the views of

[1] Stuttgart, 1898, pp. 546 + 4.

one of the great German masters, almost at the close of the century.

Rosenbusch's primary division of rocks is into four great classes :

I. Eruptive rocks ("Eruptivgesteine").
II. Stratified rocks ("Die schichtigen Gesteine").
III. Crystalline schists.
III. Primary crust of the earth ("Erste Erstarrungskruste").

Concerning the first class, it is to be noted that Rosenbusch drops the term "massig," used for twenty-five years, as less appropriate—"weniger passend villeicht"—than *Eruptive.* In the further treatment of eruptive rocks Rosenbusch does not depart from the principles and methods of the last edition of the "*Physiographie der massigen Gesteine*," and there is, therefore, no occasion to repeat the analysis of that work already given.

The stratified rocks of Rosenbusch form a class under the general idea expressed by Lossen. It is pointed out by Rosenbusch that the character of the materials of stratified rocks is not so intimately related to the essence ("*Wesen*") of the mass as with eruptive rocks, and hence there is no corresponding firm basis for their classification.

Stratified rocks are divided into seven families, as follows:

1. *Precipitates*—including rock salt, gypsum, anhydrite, barite, etc.
2. *Psephites and Psammites* or clastic rocks.
3. *Siliceous rocks*—not clastic, partly chemical deposits, partly organic, partly of undetermined origin, *e. g.*, lydite, diatomaceous earth, sinter, etc.
4. *Carbonate rocks*—including limestone, dolomite, and impure calcareous rocks, loess, etc.
5. *Iron rocks*—including spathic iron, spherosiderite, brown hematite, bog ore, etc.
6. *Clay rocks*—including clay, clay-slate, phyllite, etc.
7. *Porphyroid.*

Appendix. Coals, etc.

In this arrangement Rosenbusch attempts no logical construction of anything which can be called a system. As he frankly admits, the porphyroids are metamorphic rocks, often associated with the crystalline schists, and as they were not

derived from sediments it is incorrect to place them in the stratified class. In the necessity for placing coals and other carbonaceous rocks in an *appendix* is further evidence that the arrangement under discussion is inadequate.

The Crystalline Schists are defined by Rosenbusch as alteration products of eruptive or sedimentary rocks. Both dynamic and contact metamorphism are recognized as effective in producing them. Rosenbusch further asserts that the changes have been entirely structural and molecular, and not chemical, hence by quantitative analysis of a metamorphic or crystalline schist one may arrive at a knowledge of the composition of the original rock, eruptive or sedimentary, from which that schist was derived. The designation *metamorphic rocks* is acknowledged to be appropriate.

The Crystalline Schists are treated under the following heads : (1) Gneiss, (2) Mica schist, (3) Talc schist, (4) Chlorite schist, (5) Amphibole and pyroxene rocks, (6) Serpentine, (7) Lime series, (8) Magnesian series, (9) Iron series, (10) Emery.

Concerning these groups Rosenbusch remarks :

> In most of these large groups of the Crystalline Schists, which are held together mainly through mineral composition, there are united rocks of fundamentally different genesis. Therefore they are not natural but rather artificial series. For the replacement of these artificial groups by natural ones there is lacking, at the present time, both necessary breadth of experience and maturity of judgment, from which the need for reform in various directions is evident.[1]

Believing that the natural classification of metamorphic rocks must develop by the historical method, with the increase of knowledge, Rosenbusch proposes, as a step in the desired direction, to apply the prefix *ortho* to the names of gneisses derived

[1] In den meisten dieser grossen Gruppen von Krystallinischen Schiefern, welche lediglich durch gleichen oder ähnlichen Mineralbestand zusammengehalten werden, sind genetisch grundverschiedene Gesteine zusammengefasst. Daher sind sie nicht natürliche sondern künstliche Reihen. Zur Umgestaltung dieser künstlichen Gruppen in natürliche fehlt zur Zeit noch einerseits die erforderliche Breite der Erfahrung, andererseits die Reife des Urtheils und damit das Bedürfniss nach Reform in weiteren Kreisen. — *Elemente*, p. 461.

from eruptive rocks, and *para* to those derived from sediments. The enumerated divisions of Crystalline Schists are not defined in a systematic manner, and even the terms *gneiss* and *schist* are given no definite meaning.

The fourth class of rocks advocated by Rosenbusch, on genetic grounds, *the original crustal rocks*, is considered by him as not certainly represented by any known rocks. But it appears to him probable that they possess the habit of the crystalline schists.

Johannes Walther, 1897.—An outline of a general classification of rocks upon a logical and consequent basis was presented to the Seventh International Congress of Geologists in St. Petersburg, in 1897, by Johannes Walther.[1] Although but an outline of a system this proposition deserves attention as the most consistent effort yet made to formulate a system of petrography co-ordinate in method for different classes of rocks.

Walther starts from the consideration that the growth of petrographic system in recent years has been very one-sided, a fact recognized by all. He believes that a natural arrangement of igneous rocks has been provided by petrographers of the modern school, while sedimentary and metamorphic rocks are still arranged upon old and partly incorrect bases. Aiming to secure a logical system, Walther formulates the following principles which he thinks should be observed in the classification of rocks:

I. The petrogenesis of recent deposits and the direct observation of actual processes are the fundamental principles of classification.

II. Every older rock has *primary* characters given it at its formation, and secondary ones derived by *diagenesis* or *metamorphosis*.

III. The derived characters may so change the type of the rock as to become "essential," while the primary characters become "accessory."

IV. In spite of this last condition only the primary characters should determine the principal groups of petrographic system.

V. Next to the primary lithologic characters the primary form of occurrence has a classificatory value. There must be distinguished, therefore, Unstratified, Stratified, and Dike rocks.

[1] "Congrès géologique international," *Compte-Rendu de la VII session, St. Pétersbourg, 1897*, p. 9 (issued in 1899).

VI. The characters derived by chemical diagenesis, or by contact and pressure metamorphism, serve for distinction of lesser groups.

VII. The altered rocks are to be placed with their original types.

The system proposed by Walther, in accordance with the stated rules, is in outline the following:

I. Mechanical Rocks. Composed of older rock fragments; divided by form and size of the fragments into 5 subgroups:
  1. Breccias: (*a*) Unstratified; (*b*) Stratified; (*c*) Dike form.
  2. Conglomerates: (*a*) Stream deposits; (*b*) Delta deposits; (*c*) Strand deposits.
  3. Moraines.
  4. Psammites — sands, more or less sorted: (*a*) Quartzose sandstone; (*b*) Arkose; (*c*) Olivine sands; (*d*) Iron ore sands, etc.
  5. Pelites — of minute particles: (*a*) Unstratified; (*b*) Stratified — fresh-water; (*c*) Stratified — marine.

II. Chemical rocks. Precipitates or sublimates.
  1. Calcium carbonate.
  2. Calcium sulphate.
  3. Sodium chloride.
  4. Haloid Salts ("Abraumsalze").
  5. Silica.
  6. Carbon.
  7. Ores.

Further divisions are made by occurrence — as Stratified, Unstratified, or in Dikes.

III. Organic rocks. Formed of the remains of animals or plants.
  1. Limestone: (*a*) Unstratified — Reef limestone; (*b*) Stratified — derived from plants (algæ); (*c*) Stratified — derived from animals.
  2. Silica: (*a*) Diatomaceous earth and land plants; (*b*) Diatomaceous earth with marine fossils; (*c*) Radiolarian earth.

IV. Volcanic rocks — Consolidated magmas.
  1. Lavas — Compact rocks: (*a*) Unstratified — deep-seated rocks; (*b*) Stratified — Effusive rocks; (*c*) Dike rocks.
  2. Tuffs — Magmas consolidated in small fragments: (*a*) Unstratified, in streams, not sorted; (*b*) Unstratified, subaqueous accumulations near vent — water tuffs; (*c*) Stratified, sorted according to specific gravity; originally inclined; traversed by dikes — tuffs about a land volcano; dry tuffs; (*d*) Stratified, alternating with marine deposits, without dikes; tuffs of sedimentation; (*e*) tuff dikes or chimneys.

In connection with these primary rocks the author mentions,

as examples, many of the forms derived from them by diagenesis or metamorphosis, but does not outline the system for discriminating and naming these alteration products. Some of the metamorphic rocks, such as gneiss and mica schist, may be formed from several primary rocks.

The proposition made by Walther is manifestly rather the work of a geologist than of a petrographer (as was pointed out by Brögger in discussion, when it was presented to the Congress). Like many discussions of principles concerned in the systematic problem, it is not sufficiently worked out to show a practical result, and does not fully test the adaptability of the chosen factors for petrographic system. But it seems to the writer that in this renewing of effort to treat the non-igneous rocks in logical systematic manner lies ground for hope that something more than an arrangement for convenience may develop during the early years of the twentieth century.

Returning to a consideration of the principles adopted by Walther, it may be remarked that the first one would be excellent if the processes of rock formation were all open to examination. Unfortunately, they are not so, in all cases. Many igneous rocks and nearly all of metamorphic origin have resulted from processes we cannot see in operation and can only imperfectly imitate in experiment. The fourth rule is not a necessary consequence of the facts stated under II and III. It is open to argument whether the processes which originally produced a rock are more deserving of recognition in petrographic system than the processes which have greatly or entirely changed the characters and perhaps even the composition of the original mass, making the rock now accessible to our studies.

As to rule V it can hardly be said to warrant the application made of it, in establishing the three divisions of unstratified, stratified, and dike forms for all kinds of rocks. Where the relations expressed by these terms have some genetic connection with the properties of the rocks they may perhaps be adaptable to classificatory purposes, but there is no logical reason for applying this principle in unqualified form.

The system of Walther seems specially intended to express the changes rocks undergo rather than their characters as now seen, and it is not apparent that the author had in mind the apt and logical analysis of the broad science of rocks which we owe to Naumann.

That the general treatment proposed by Walther for igneous rocks, in naming them volcanic, and making the primary division into unstratified, stratified and dike rocks, has many objections will be sufficiently clear from the preceding discussions of this review. The same is true of the assumption that there exists a satisfactory system for the classification of igneous rocks. The definition of tuffs as composed of magma consolidated in small particles certainly applies to but a small part of the pyroclastic deposits.

SUMMARY.

The science of petrography, the systematic and descriptive science of rocks, was first fairly outlined by von Leonhard (1823) and Brongniart (1827) through the distinction between the rock and the geological terrane, and the setting up of logical classifications for the former. Neither of these masters gave the science a name.

The systems of von Leonhard and Brongniart necessarily used the condition of ignorance concerning the character of many rocks as a ground for classification. With the increase of knowledge of rocks there have been many attempts to apply new information to systematic purposes. Since both the geological relations and the properties of rocks are highly varied many unlike systems have been proposed during the century, expressing individual opinions as to the relative importance or adaptability of principles for the end in view. Up to the present time, however, no comprehensive classification of rocks has been proposed which even pretends to be natural or logically consistent in all its parts.

When we view past petrographic systems, to judge as to how far they possess natural or artificial features, it is first of all to be noted that the system of Cordier is practically the only one starting from the conception that rock species are natural

units and that classification consists in the grouping by more or less artificial means of these fundamental units. Others have sought to make the system of rocks in some degree natural by applying geological factors of occurrence, or genesis, as bases of classification. The view is apparently held by some that in time there will be a comprehensive system expressing all important relations of rocks and that until that result is achieved all arrangements must be regarded as unsatisfactory and temporary.

It appears to the writer that those who hold this attractive and apparently philosophical view may not have in mind the distinction between the formal unit and the rock substance of that unit, or that distinction between the various cross-classifications of petrology and the one system of petrography, with which the nomenclature is specially connected.[1] The belief expressed by Lossen that "geological relations must be recognized as petrographical relations" and the assertion by Rosenbusch that "petrography is an historical science" illustrate this point.

If the system of petrography is to be hierarchical, as the writer believes it should be, the natural element in system is to be provided for in the judicious selection of broad geological factors so related to important characters of rocks that the completed system in the construction of which those characters have been used, will have a logical and appropriate co-ordination and sequence of parts. That this aim has not controlled in the past is evident from the following partial list of designations given to the rocks which are actually consolidation products of magmas: "Composite, crystalline-granular, and porphyritic" (Zirkel); "Non-clastic, composite, massive" (Zirkel); "Composite-simple" (von Lasaulx); Unstratified, Anogene, Massive, Plutonic, Volcanic, Eruptive, Igneous. Here are expressed a number of natural relations, to be recognized in the proper place, but only the last term refers directly to the relation most appropriate for petrographic system. It was not the fact that eruptive force was

[1] See "The geological versus the petrographical classification of rocks," by WHITMAN CROSS, JOUR. GEOL., Vol. VI, p. 79, 1898.

exerted to bring molten magmas to the sites of the rocks we study, but the fact of the molten condition which gave its stamp of common characters to the products of consolidation.

Arbitrary steps are necessary in the classification of such objects as rocks, exhibiting gradations in all directions. But that fact does not justify such artificial systems as many of those which have been reviewed. Among the most distinctly artificial systems are those of Cordier, Senft, and von Lasaulx; but scarcely less so, as regards igneous rocks, are those which, while using chemical or mineral composition as the basis of arrangement, use only a portion of the mass. For examples: some of the chemical classifications take only certain components into account; Fouqué and Michel-Lévy classify igneous rocks by the character of that variable portion of the magmas consolidating during the second period; Rosenbusch uses the phenocrysts only, in certain parts of his system.

The fundamental requirement that systems should be logical in construction, with consistent and consequent application of principles adopted, has been so commonly disregarded that a summary of instances in point seems unnecessary. Some of the most widely used systems of today are notably illogical as to criteria, as has been pointed out.

One of the most serious defects of modern classifications of igneous rocks is a matter of bad logic, and to this defect the writer wishes to allude once more. It is commonly admitted that the chemical composition of these rocks is their most fundamental characteristic, and many authors would apparently be glad to apply this character in classification. It is generally stated, however, that the chemical is represented by the mineral composition, and as the minerals are so prominent it is convenient to use them in system. But with no further discussion it has been the universal plan to use the minerals in so limited a qualitative way that they do not in fact express chemical composition except in a most crude and inadequate manner. This procedure is purely and simply illogical, if the intention be to represent chemical composition by the minerals of the rock.

That some factors have been introduced into classification in a manner that is quite unscientific seems plain. The age distinction is one of the factors thus abused. It has long been known that no general distinction separated pre-Tertiary and Tertiary igneous rocks. It may be that the average chemical composition of magmas erupted in successive ages has undergone some change; but neither the character of the change, nor, least of all, any special connection with the particular time limit in question, has been established. The assumption that igneous rock textures, such as the granular, porphyritic, or vitreous, are functions of geological form or place of occurrence, is known to be contrary to the facts displayed by the rocks. Both of these assumptions have been and are now used in rock classifications.

Stability of system is certainly desirable, within the bounds of reason. But it is also self-evident that a system of artificial character, in which the subjective element is dominant, can be permanent only by universal consent of petrographers, and such consent is not to be expected. It is a matter of experience that genetic theories have made systems into which they have been introduced very unstable and impossible of general adoption. The danger of using hypotheses in classification has been well characterized by von Cotta, somewhat as follows: Geology is a particularly alluring field for premature attempts at the explanation of imperfectly understood facts; indeed, such attempts are almost unavoidable in the study of this science. When one considers hypotheses simply as such, *i. e.*, as stimulants toward their possible demonstration, then they are not harmful; the danger lies therein that one may believe them already proven and rest contented.[1]

The danger pointed out by von Cotta has been illustrated in the classification of igneous rocks by such able men as von Richthofen, King, and Rosenbusch. As regards the interior of the earth, whence the molten magmas come, we cannot as yet be sure that what we regard as a law today may not be relegated to the status of a theory or even of an hypothesis tomorrow.

[1] B. VON COTTA, *Gesteinslehre*, 2d ed., 1862, p. vi.

The genetic theory has its proper field of great usefulness in the department of petrology dealing with petrogenesis. Ultimately we may hope and expect that genetic relations of igneous rocks may be available for a more natural classification than is now feasible.

Any system of classification should be broad and thorough enough to include all the objects which it professes to deal with. But the authors of many systems outlined in this review have been obliged to resort to the expedient of *appendices* to bring in rocks not otherwise provided for. Such a necessity is, at once, evidence of the inadequacy of the criteria guiding the authors of such systems.

Even in the class of igneous rocks, propositions for chemical and mineral classifications do not fully recognize the systematic importance of some of the relatively rare constituents. Chemical systems which consider all igneous rocks as mixtures of silicates, or reject magnetite as extraneous, are not comprehensive. Similarly, the schemes which do not provide for the due recognition of titanium minerals, corundum, apatite, sulphides, etc., as important constituents in some cases, are inadequate, even for present uses, and certainly do not provide for future needs which can be clearly foreseen.

In conclusion, the status of systematic petrography at the close of the nineteenth century may be summarized as follows:

1. There is as yet no comprehensive and properly systematic classification of all rocks. All so-called systems exhibit portions in which the rocks are treated in an unsystematic manner, for convenience of description and discussion. The grand divisions are not treated by similarly logical and definite methods.

2. Rocks of igneous origin have been much more thoroughly investigated than others and they have received correspondingly more definite and systematic classification. The factors used in systematic construction pertain to genesis, age, and characters.

a. The origin of the great range in chemical composition exhibited by igneous magmas, expressed in theories of magmatic differentiation, is an underlying factor of much importance in

the system of Rosenbusch, and is also seen in the desire to recognize consanguinity of the magmas of petrographic provinces, as partially worked out by Iddings and Brögger. The availability of such factors in petrographic system is doubted by many authorities.

b. While the distinction of older and younger series of rocks through different sets of names is still found in the German and French systems there is practical unanimity of opinion that the real differences between the rocks are much less fundamental than was supposed. In America, Great Britain, and elsewhere, this distinction is held to be unwarranted.

c. The chemical and mineral composition of igneous rocks and their textures are characters used as means of classification in present systems. Chemical composition *per se* is used, but only by considering a portion of some rocks, and hence fails to provide an adequate system. The broad chemical divisions used by some authors are vague and overlapping.

Mineral composition is commonly assumed to represent the fundamental chemical constitution and to be, therefore, a convenient and practicable means of expressing the latter. In practice the qualitative method of applying mineral composition in existing systems destroys its effectiveness as expressing chemical composition.

Structure is variously used in present systems. It is acknowledged to be the product of conditions, and not dependent in marked degree upon mineral development. When applied as a primary factor in classification (as by Rosenbusch) it separates things which are similar in more fundamental characters, and on this ground some authorities believe that structure should be applied in classification after the other characters named.

3. The rocks which have formed upon the surface of the earth by the destruction of older rocks may be viewed from so many standpoints, as regards the origin of materials, agencies of transportation, relations to the earth or to other rocks, characters of materials, and processes of induration, that no consistent arrangement of these objects, deserving the name of a petro-

graphic system, has been proposed. In the existing arrangements the confusion of correlating various cross-classifications into one whole is quite evident.

4. Metamorphic rocks, including all such in which the derived characters are more prominent than the original ones, defy systematic treatment at the present time. Since they have been formed from all kinds of original rocks, by many different processes, and at many sites in the earth's mass, there are many standpoints from which they may be considered, and their classification is a complex problem. Among the facts most difficult to recognize in system are the close resemblance or identity of metamorphic products from originally different rocks, and the similar correspondence between certain secondary and primary rocks. The proposition of Walther to classify all metamorphics with the masses from which they were derived is thus impracticable at the present time, even if it be thought desirable. In relation to this class of rocks systematic petrography is in the condition that its arrangements are tentative, awaiting new knowledge concerning the genesis and essential characters of the objects.

The review of the development of systematic petrography given in the preceding pages has been mainly a discussion of comparatively comprehensive arrangements or systems which have been proposed. It is, of course, true that these systems are but correlations of ideas from many sources, and a complete history of the subject would give to important discoveries of fact and to critical or creative suggestions their due weight in influencing the development of systems. But such influence is difficult to trace, and to have attempted such a history would have involved the expenditure of much more time than the writer could devote to the subject. For this reason a large number of important essays, bearing upon certain features of classification or devoted to discussion of principles, have been left unnoticed because they were not accompanied by general

systematic propositions. Among the essays thus disregarded are notable ones by Rosenbusch, Brögger, Becke, Michel-Lévy, Teall, Iddings, Spurr, Turner, and many others.

The telling effect of searching investigations touching controverted points of fundamental significance and of the judicial remarks of those who have carried out such studies is often much greater than either author or reader is aware. In the course of time the influence exerted by a succession of investigations becomes evident in some proposition for the revision of classification. Petrography has thus come to its present condition by a steady natural evolution, and its future growth must undoubtedly follow the same course.

WHITMAN CROSS.

AN ANALCITE-BEARING CAMPTONITE FROM NEW MEXICO.

During the summer of 1899 the writer was a member of the field class of Professor R. D. Salisbury, of the University of Chicago. The party visited the Grand Canyon of the Colorado, stopping on the way at several localities of interest. The first halt was made at Las Vegas, New Mexico, where Miss Inez Rice, a member of the class, guided the party to the butte which forms the subject of this paper. I take pleasure in acknowledging my indebtedness to Professor Salisbury for assistance in the field, and to Miss Rice for suggestions on the general geology of the region. The petrographic work was done in the laboratory of Columbia University, and thanks are due to Professor Kemp for much kindly advice and assistance. Special thanks are also due to Dr. F. Bascom and to Dr. H. S. Washington, for reading this paper and for suggestions concerning it. The analysis was very kindly contributed by Mr. George A. Goodell, of the College of Physcians and Surgeons; the photograph which forms the accompanying illustration (Fig. 1) was obtained through the courtesy of Mr. K. M. Chapman, of Las Vegas. Special thanks are due to both these gentlemen.

The Las Vegas region exhibits the general geology and physiography typical of the eastern border of the Rocky Mountains. In it are represented the two great geographical provinces, the Great Plains and the Cordilleran region. These two geographical districts are in close correspondence with the geological structure.

The Cordilleran section consists of a doubtfully Archean floor, upon the base-leveled surface of which Carboniferous limestones were deposited. This represents an overlap beyond the Cambrian which underlies the Carboniferous farther north. Unconformably above the Carboniferous, and situated along

the line bounding the two geographic regions, are the Red Beds of Permo-Triassic age, with their associated gypsum deposits. The relation of physiographic form to geologic structure is most excellently exhibited. The hard granitic rocks stand out as rugged peaks, with occasional gentle slopes where the Carboniferous limestones are left on their flanks. The Red Beds represent the softest rock of the region, and the position of this outcrop is marked by a valley.

FIG. 1.—View of Camptonite butte, Las Vegas, New Mexico.

The contrast between the Cordilleran region and the Great Plains is both structural and physiographic. The latter region is underlaid by the Dakota and Colorado formations, with occasional remnants of the Montana and Laramie. Except near the mountains, the Cretaceous formations are nearly horizontal, but there they are upturned. Throughout Colorado and northern New Mexico, the outcrop of the Dakota sandstone forms a series of ridges locally known as "hog-backs." Las Vegas is situated at the eastern base of one of them.

About four miles slightly north of east of Las Vegas there is a little butte of igneous rock of exceptional interest. The structure of the rock and its occurrence indicate that it was intruded into the Cretaceous beds at a considerable depth, though it now stands somewhat above its surroundings.

The rock is probably to be referred to the group described by Professor Pirsson[1] as "the analcite group of igneous rocks," and no similar rock has hitherto been described from this region. Similar masses are mentioned in the Elmoro folio, and termed "lamprophyres," hence it is probable that future investigation will bring to light other related intrusions.. No elaeolite syenite nor other rock that could be related to these lamphrophyric intrusions has yet been found; hence the relationship of the rock and the magmatic history of the group to which it belongs, remain as problems to be studied in connection with the further investigation of the region.

The rock is medium grained, of a general gray appearance, with large crystals of hornblende and augite which can readily be seen with the naked eye. In the predominating phase of the rock, these crystals are about $.8^{mm}$ in length, but in occasional segregations they reach a length of as much as 1^{cm}. These ferro-magnesian minerals lie in a gray groundmass which on microscopical examination proves to be mostly plagioclase.

In thin section the rock is seen to be porphyritic, with phenocrysts of augite and of hornblende, occurring in equal amounts, and of rarer biotite. The groundmass consists of a network of plagioclase, with an isotropic substance which is probably analcite, filling the interstices between the plagioclase laths. Magnetite, ilmenite, and apatite are also present.

The pyroxene is always idiomorphic, occurring in large phenocrysts and also to a small degree in the groundmass. It is a pale greenish-violet, normal augite, and is very faintly pleochroic. The cleavage is well defined. Some of the porphyritic crystals show a slight zonal structure. Twinning is very common and usually the twinning plane is $\infty P \frac{1}{\infty}$ (100). Certain complicated intergrowths also occur, which probably also represent twinning, the twinning planes being $-P \frac{1}{\infty}$ (101) and P_2 (122) (Fig. 2).

[1] L. V. Pirsson, Jour. Geol., Vol. IV, 1896, pp. 679–690.

Intergrowths of augite and hornblende are common, and so are occasional inclusions of augite in hornblende (Fig. 3).

The amphibole is idiomorphic, occurring only as a phenocryst. It is of the basaltic hornblende type. The pleochroism is very strong, **c** and **b** = deep brown, **a** = pink. The terminal faces are usually lacking. These phenocrysts exhibit the characteristic cleavages of hornblende. In a few slides a very small amount of secondary hornblende was found associated with the augite, but the prevailing hornblende is certainly an original constituent.

Mica occurs in small quantity, as irregular shred-like phenocrysts. It is a very pleochroic biotite, changing from brownish-black to reddish-brown.

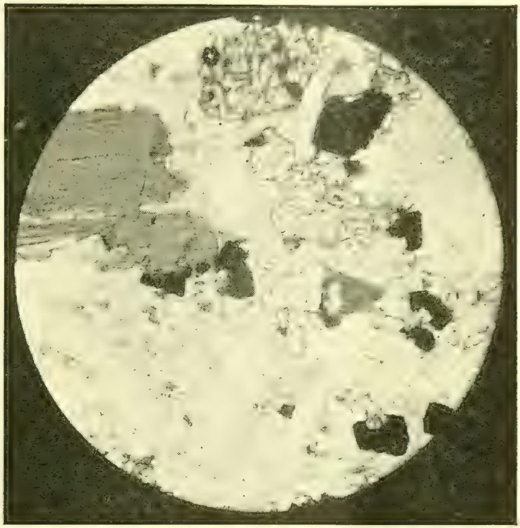


FIG. 2.—Twinned aggregate of augite.

The feldspar occurs in the groundmass, as lath-shaped, polysynthetically twinned crystals. They form an interlocking network which is difficult of interpretation; a number of readings of extinction angles on the *P* face varied from 15° to 35°, indicating a plagioclase rich in lime (bytownite or anorthite). The presence of this plagioclase is further indicated by the high lime percentage of the analysis.

Lying between the laths of feldspar is an isotropic substance which appears to be analcite. It occurs in such small areas and is so thoroughly mixed with the groundmass that determinations of it were necessarily imperfect. In one instance it exhib-

ited the cubical cleavages of analcite. The rock was fresh and this mineral was undoubtedly of primary origin, being apparently the last to crystallize and filling all interstices. The larger grains are free from inclusions, but are sometimes surrounded by rings of magnetite and ilmenite grains; the smaller grains often contain a fine black dust suggestive of leucite. This structure appears to be identical with that described by Mr. Cross in the case of an analcite basalt.[1]

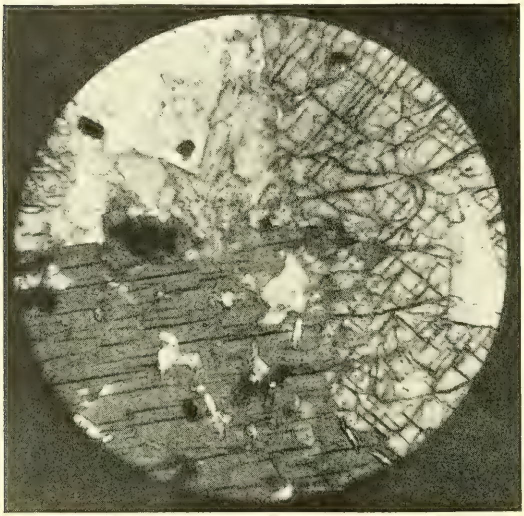


FIG. 3.—Intergrowth of hornblende and augite, with inclusions of augite in hornblende.

Magnetite and ilmenite are abundantly distributed in large crystals. Apatite occurs in the form of elongated prisms with truncated corners, and is common throughout the groundmass.

Very little alteration could be seen in any of the constituents. As already mentioned, very small amounts of secondary hornblende occur, derived from the augite. The plagioclase is occasionally slightly sausuritized, and small quantities of secondary epidote are occasionally found. The rock as a whole is, however, remarkably fresh.

The most noted district for rocks of this class is the neighborhood of Lake Champlain, where they have been made known principally through the work of Professor Kemp.[2] The writer

[1] WHITMAN CROSS "An Analcite-basalt from Colorado," JOUR. GEOL., Vol. V, 1897.

[2] J. F. KEMP, "Trap Dikes of Lake Champlain," *Bull. 107, U. S. Geol. Surv.*

has compared the slides of the Las Vegas rock with those from the Champlain region, and also with those from Campton Falls,[1] from Whitehall and Fairhaven, Vt.,[2] and several neighboring localities; and with a series from the Black Forest in Germany. When all these camptonites were studied and compared with the Las Vegas rock, a marked difference in texture was seen. The Las Vegas rock is coarser grained, the phenocrysts more abundant, and there is a less marked difference in size between phenocrysts and groundmass. This is what might be expected since the eastern rocks occur in dikes, and the Las Vegas one in a stock. The eastern rocks are all considerably altered, containing calcite, serpentine, delessite, and secondary analcite. The Las Vegas rock is remarkably fresh. This comparison gives strong indirect evidence of the primary character and analcitic nature of the isotropic substance; the rock is too coarse-grained for it to be a glass and too fresh for it to be a secondary product.

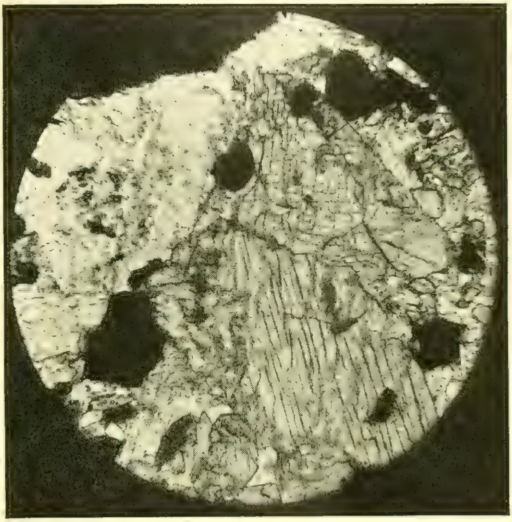


FIG. 4.—Typical section of the Las Vegas Camptonite, showing phenocrysts and groundmass.

The term "Camptonite" is commonly applied to the plagioclasic lamprophyres, in distinction from minette and vogesite which are orthoclasic. Common usage[3] has restricted the term Camptonite to the lamprophyric plagioclase rocks with horn-

[1] Described by J. W. HAWES, *Amer. Jour. Sci.*, ser. 3, Vol. XVII, p. 148.

[2] Described by J. F. KEMP, *Amer. Geol.*, Aug., 1889.

[3] F. BASCOM, *Nineteenth Ann. Rept. U. S. Geol. Surv.*, Part III.

ANALYSES.

	I.	II.	III.	IV.	V.	VI.
SiO_2	44.48	38.45	41.94	45.76	45.11	42.08
Al_2O_3	20.43	19.68	15.36	20.48	19.67	20.88
Fe_2O_0	9.72	4.01	3.27	1.99	4.32	6.77
FeO	2.18	11.15	9.89	4.18	8.57	3.17
CaO	10.35	9.37	9.47	11.57	10.45	12.48
MgO	5.51	6.65	5.01	8.50	5.65	6.85
TiO_2	.57	....	4.15	....	0.21	....
MnO	....	trace	0.25	....	....	....
K_2O	1.59	1.72	0.19	0.80	0.64	0.44
Na_2O	3.61	2.77	5.15	3.56	3.87	3.37
Loss on ignition	3.21	....	3.29	2.80	....	....
H_2O	....	1.49	....	....	0.17	3.18
CO_2	....	4.82	....	....	....	....
P_2O_5	....	....	....	....	0.25	....
Total	101.65	100.11	100.44	99.64	100.07	99.22

I. The Las Vegas rock.

II. Camptonite from Campton Falls, N. H. Published in *Bull. 148, U. S. Geol. Survey*, p. 67.

III. Camptonite from Campton Falls, N. H. J. W. Hawes, *Am. Jour. Sci.* Ser. 3, Vol XVII, p. 150.

IV. Gabbro from Rosswein, Saxony. Landwirthsch Versuchs station 40, 1892.

V. Diorite from Lindenfels, Hesse Darmstadt. Chelies & Klemm, *Erläuterung zur Geologischen Karte von Hesse*, 1896.

VI. Basalt, middle flow, Carlsbad, Bohemia. *Jahrbuch der Königlich Kaiserlichen Gesellschaft Kunstaustellnng*, Vol. XL, p. 345, 1890.

blende as the principal ferro-magnesian mineral; augite camptonite is applied to those in which augite equals or exceeds hornblende; analcitite to those containing primary analcite. Rosenbusch's latest definition (1901) includes augite as an essential constituent of a camptonite, thereby departing from the original type of Hawes in which hornblende predominated.

In the case of the Las Vegas rock hornblende and augite occur in approximately equal quantities. Since the tests for analcite were not conclusive, the rock could not be called an analcitite. It seems most logical to regard equal amounts of hornblende and of augite as distinctive of a camptonite, restricting augite camptonite to those with augite in excess. The Las Vegas rock can thus most logically be termed an analcite bear-

ing camptonite. I am indebted to Dr. Bascom for suggestions on nomenclature.

The accurate recalculation of the analysis proved impossible, owing to the combination of minerals containing the same oxides. The high Na_2O is a strong indication that the isotropic constituent is analcite, and this is further indicated by the optical character of the plagioclase; it is near the anorthite end of the series, hence, has low Na_2O. Microscopically hornblende, augite, and plagioclase are present in approximately equal amounts.

Analyses two and three are typical camptonites, and it will readily be seen that the Las Vegas rock is close to them chemically. Analyses four, five and six are of rocks of other groups which are also similar chemically. The likeness of the last three was kindly suggested by Dr. Washington.

I. H. Ogilvie.

Geological Department,
Columbia University.

HOLYOKEITE, A PURELY FELDSPATHIC DIABASE FROM THE TRIAS OF MASSACHUSETTS.[1]

In the monograph of the three river counties in Massachusetts,[2] the writer described a "white trap" which occurs only in scanty fragments in a bed of agglomerate interstratified in the sandstone, a few feet above the surface of the great Holyoke trap sheet at the east foot of Mount Tom, and a few rods north of the station of the electric road going up onto the mountain. The small angular fragments of the volcanic rock are scattered rather distantly in the calcareous red sandstone, and seem closely like a white, horny limestone spotted with chalcopyrite. They include fragments of the coarse sandstone below the Holyoke trap sheet, up through which they must have come, and these inclusions are much coarser than the sandstone in which they are included. The weathered surfaces show the rock to be finely amygdaloidal, and acid brings out in the interior the same structure which can indeed be seen, by attentive study with a lens, on a freshly broken surface. A few grains of yellow ore appear here and there in the body of the rock and in the round cavities, and rarely the reflection of a twinned plagioclase lath is visible.

The thin section shows so exactly every structure of the diabase except those dependent upon the presence of iron in form of magnetite and augite that one cannot help associating it closely with the adjacent Holyoke sheet, as I have formerly done by calling it a "white trap." Even the presence of much chalcopyrite is characteristic. Under the microscope the texture is exactly that of the trap of the large sheets minus the augite. It is especially like the superficial portion of the Deerfield sheet exposed at Cheapside.

There is an ophitic network of very fine plagioclase needles

[1] Published by permission of the director of the United States Geological Survey.

[2] *Monograph XXIX, U. S. Geol. Surv.*, 1898, pp. 365–474.

of two sizes, both elongate blades with ragged ends and irregular sides; the finer about 0.03^{mm} long; the latter having sometimes quite regular crystalline outlines. Scattered in this network are distant feathery groups of plagioclase crystals of first consolidation which are just visible to the eye. One of these larger crystals cut parallel to M (010) showed the optical figure of albite.

All these feldspars are lightly dusted with blades and grains of a secondary mineral of low polarization, probably zoisite. And there is a very little granular limonite scattered through the rock, but no accumulation of it, or appearance of any chloritic mineral to indicate the former presence of magnetite and augite or hornblende. There are no brightly polarizing blades that could be referred to a colorless bisilicate.

As in the peculiar red diabase from Cheapside, near Greenfield, described in the monograph[1] above mentioned, the small round steam cavities are lined by a secondary growth of albite in fresh limpid crystals.

There are other fragments associated with the Holyokeite which are black, aphanitic, and show under the microscope a similar texture, but contain large spots of a green chloritic mineral.

The chemical composition of the rock is shown by the following analysis I, by Mr. Hillebrand.

If we follow the calculation of the analyst and assign the sulphur to 0.40 chalcopyrite and 0.06 per cent. pyrite, and then calculate the phosphoric acid as apatite, the titanic acid as ilmenite, the potash as orthoclase, and assign the carbonic acid to the magnesia and most of the calcium, we shall account for 30 per cent. of the analysis.

It is interesting that the remaining 70 per cent. has the composition of an albite of exceptional purity, and the only feldspar determined in the slide was albite.

SiO_2 - - -	67.89
Al_2O_3 - -	20.87
Na_2O - - -	11.24
	100.00

[1] *Loc. cit.*, p. 431.

	I.	II.	III.
SiO_2	53.83	60.13	51.78
Al_2O_3	16.36	20.47	12.79
Fe_2O_3	0.89[1]	1.04	3.59
FeO		.72	8.25
MgO	.13	1.15	7.63
CaO	9.81	2.59	10.70
Na_2O	7.89	9.60	2.14
K_2O	1.58	1.06	0.39
H_2O —	.15	.....	.63
H_2O +	.36	.....	.....
TiO_2	.86	trace	1.41
ZrO_2	.02	.....	.....
CO_2	7.47	3.44 (Ignition, includes H_2O)	.....
P_2O_5	.11	.....	.14
S	.17[2]	.....	.....
MnO	a little lost	trace	0.44
BaO	none	.....	.....
SrO	none	.....	.....
Li_2O	none	.....	.....
CuCu	.14[2]	.....	.....
	99.77	100.20	99.89

I. Analysis of Holyokeite made by Mr. Hillebrand, of the United States Geological Survey.

II. Analysis by Dr. H. S. Washington of the acid dyke in the Connecticut Trias, described by Mr. E. O. Hovey and mentioned below. *Specific Gravity* at 11° C = 2.63.

III. Analysis of the normal Triassic diabase of West Rock, New Haven, by Mr. G. W. Hawes. *Am. Jour. of Sci.*, III, IX, 186, 1875.

[1] The figure here given (0.89) includes not only ferric and ferrous iron, but also that in combination with sulphur, as ($CuFeS_2$) and possibly a little FeS_2. Because of the sulphide FeO could not be estimated. (Hillebrand.)

[2] Taking the Cu as a basis the sulphides figure out 0.40 per cent. $CuFeS_2$. I cannot say that there is any FeS_2 present. The mass of the sulphide seems certainly to be chalcopyrite. (Hillebrand.)

The whole rock will then contain, roughly speaking:

Apatite	0.23
Dolomite	0.52
Calcite	16.42
Orthoclase	9.41
Albite	70.25
Ilmenite	1.63
Chalcopyrite	.40
Pyrite	.06
	100.00

This ignores the water which might have been calculated, perhaps, as kaolin, since there is no visible chloritic mineral or zeolite. It ignores also a third of a per cent. of CaO, which now forms calcite, and which with the rest of the calcium was present in the original rock, perhaps for the most part, as anorthite; that combined with the albite formed several intermediate varieties of plagioclase.

This calcium may have been present in part as a sahlite. In the latter case it might have been called a sahlite-diabase, but in a sense very different from that in which the word has been used by Törnebohm for a diabase in which the sahlite is quite subordinate to the abundant augite. The rock in which the fragments are embedded is, however, so calcareous that some part of the calcite may have been introduced into the amygdaloidal cavities from without.

The leucophyr of Gümbel is, as compared with diabase, "a remarkably light-colored rock with saussuritic feldspar, pale green augite (without hornblende and rarely with red-brown augite), with a chloritic constituent in large quantity and tabular ilmenite." This seems to me quite plainly an altered diabase, and different from this non-ferruginous rock.

The only similar rock that has been described from the American Trias is the acid dyke discovered by Mr. E. O. Hovey in the new cut on the Shore Line Railroad, in the eastern part of New Haven, provisionally referred by him to keratophyr. It is distinctly different from the type described here.[1] It is brick-red like the Cheapside trap, or grayish like the second variety described above, which accompanies the white trap.

It is largely feldspathic and the ferro-magnesian minerals are absent, but chlorite is present in considerable abundance, and the fields of chlorite and calcite "for the most part have definite outlines which strongly suggest the original presence of phenocrysts of pyroxene (augite) in the rock." Mr. Hovey remarks that spherocrystalline structure was observed in some places. This may have been the structure that I have interpreted above

[1] *Am. Jour. Sci.*, ser. 4, Vol. III, p. 287, 1897.

as a growth of secondary albite in steam holes. This suggestion depends upon a comparison with material of exceptional excellence from Cheapside where the whole process could be followed and where the perfect crystals of albite could be isolated and determined in heavy fluid. The chemical differences between the two rocks are many, as may be seen by comparing the analyses given above. In the matter of SiO_2 and Al_2O_3, the Holyokeite is intermediate between the keratophyr of Hovey and the normal diabase.

The minute quantity of iron (not enough to satisfy the S and TiO_2) and magnesia, show that there can scarcely have been a trace of augite or sahlite present in the Holyokeite, while the keratophyr may have contained much bisilicate. Finally the discrepancy in the CaO is decided, even after saturating the CO_2, and would demand, considering also the smaller amount of SiO_2, a somewhat larger proportion of anorthite in the Holyokeite, while the larger amount of K_2O would demand for it a greater amount of orthoclase or anorthoclase.

The Holyokeite may then be looked upon as representing a limiting form of the diabase series where the bisilicates are wholly wanting.

B. K. Emerson.

THE LANDSLIDES OF MT. GREYLOCK AND BRIGGSVILLE, MASS.

A study of the topographic and geologic maps of Mt. Greylock will show where, theoretically, landslides would be most likely to occur. Both the large and small slides on this mountain are where, in theory, they should be. These slides are typical of one class, and the one at Briggsville of another.

The scarring of the mountain side by this agency is a very striking feature of the landscape, as one looks west from the Hoosac range and from the Hoosic valley for two or three miles on either side of Adams. The eastern side of Greylock is the steepest on the mountain, rising 1400 feet in two-fifths of a mile. It was on this slope, the base of which is about two miles west of Adams, that the land slipped. In all there are three large and eight small landslides within a mile.

The facts concerning the conditions at the time at which the landslides occurred were gathered largely from persons in the vicinity of Adams, but especially from Mr. C. O. Gould, whose farm is located at the foot of the main slide. The facts are as follows: During July and August, previous to August 20, 1901, the date on which the slides occurred, 12.92 inches of rain fell, being 5.8 inches above normal. At about three o'clock on the afternoon of the 20th a very heavy rain, spoken of usually as a cloudburst, began to fall, and lasted until seven o'clock. The record for this period at Williamstown (on the other side of the mountain) is 2 inches; at Mt. Tom, 3.42 inches. The water in the creek at the foot of the mountain rose very rapidly until it was as high as it had ever been noticed. When the slide occurred the stream became "a torrent 75 to 100 feet wide, 10 feet deep, and filled with trees." Five or six acres of the farm were covered with sand and bowlders, some of the bowlders being 4 feet in diameter.

Mt. Greylock, showing landslides. (The steepness is not well shown.)

The middle slide came first, and the large one to the north next. The time of the occurrence of the large slide to the south was not noticed, but all must have occurred within a few minutes of each other.

The mountain in this place is made up, above, of a mica schist (Greylock schist), and, below, of a rotten micaceous limestone (Bellowspipe limestone). The slope is covered with loose talus and earth, upon which is a sparse growth of trees.

The north landslide occurred at the road near the top of the mountain, where the slide is about 50 feet wide, and extends for 1500 feet down the mountain side. It gradually widens until at the base it is about 200 feet wide.

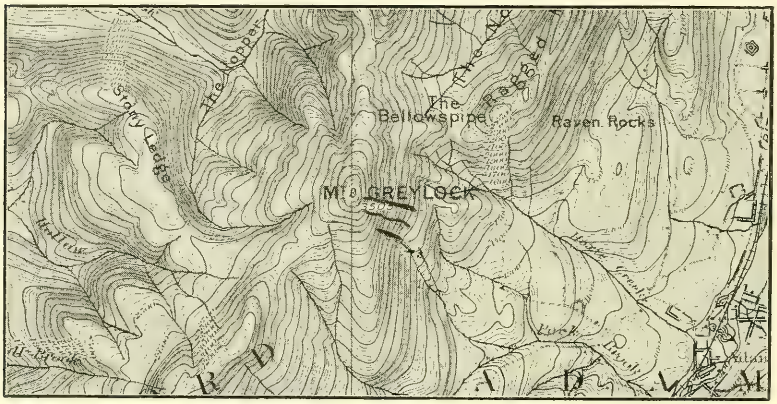
From the above it will be seen that all of the conditions were favorable for a landslide; the steepness of the slope, the fissile character of the rock, the loose material of the mountain-side wet with the unusually heavy summer rain. All that was needed to cause a slipping of this loose material was a large quantity of water to add to the weight of the mass, and at the same time act as a lubricant. The destructive force of the water was caused by the natural drainage of an unusually heavy rain, and by the water brought down and squeezed out of the mass which slid down the mountain-side. There is no evidence that a dam was formed. In the ravine through which the water flowed the water was in places 25 feet deep, as shown by the overflow.

The removed material was not piled up with a backward slope toward the mountain, as is usually the case, the great quantity of water being sufficient to remove a large part of the débris so that much of the rock and earth was carried to and deposited in the valley below.

The landslide at Briggsville is more complex. Back of the woolen mills of Strong, Hewatt & Co., and on the west bank of Beaver Creek, one sees stratified blue clay tilted at all angles from a 90-degree to an almost horizontal position. A pier is raised 4 feet and tilted to the west, and the dam to the north of the mill is raised several feet on the west side. The tilted area

is about 325 feet long and 33 feet wide. To the west of this is an excavation from which the material in the creek bed was derived. This cavity is some 320 feet in length from east to west, and about 30 feet lower than the original surface.

The history of the phenomena is as follows: During 1895 a spring, called a "geyser" in this vicinity, broke out with considerable force. The water contained a great deal of sediment, (finely divided blue clay) which was at first "as thick as pea



Topographic map of Greylock with position of the three large landslides.

soup" and contained large quantities of decayed roots. The muddy water was of sufficient volume to so contaminate the water of Beaver Creek as to render it unfit for the use of the Windsor Print Works.

The land above the spring gradually sank as the bank was undermined and with each subsidence of the surface the spring moved back toward the high bank to the west. Before the sinking occurred growing trees sank beneath the surface, in an upright position, and poles could be driven down several feet with little effort. During a flood in March, 1901, the bridge pier was tilted, the dam was raised, and the clay appeared in the creek bed. This land continued to rise for several months.

The explanation is as follows: The sediment in the water was produced by the breaking and fracturing of the clay bank,

which fracturing so loosened the clay that it could be carried away in suspension. This continued until a large quantity of clay had been removed from a stratum immediately underlying the surface sod. The most evident explanation for the slipping of the clay and its uptilting in the stream bed is that a stratum of blue clay rested on an inclined plane which was rendered slippery by the water of the spring. This stratum was separated from the surface sod by the washing away of the clay between them. When it slipped it was stopped either by the former rock bank of the stream or by some other obstacle, the slope and weight being sufficient to push the clay up from the stream bed and to raise with it the pier and part of the dam.

After the last slipping the muddiness of the water was greatly lessened showing that the movement of the ground had almost ceased. Since then, however, the amount of sediment in the water has increased, indicating that a further fracturing is in progress.

H. F. Cleland.

Williamstown, Mass.

NIAGARA METEORITE.

In the winter of 1900 I was informed by Mr. Vennor, a young mineral collector of Rochester, N. Y., that he had seen in the possession of one of his friends, now living in this city, what he supposed to be a small iron meteorite, which had been picked up on a ranch in North Dakota, some years before. After some persuasion Mr. Vennor succeeded in getting his friend to permit me to examine the specimen, which I saw at a glance was a meteorite with marked octahedral cleavage where it had been broken, and finally purchased it for Ward's Natural Science establishment.

This meteorite, which belongs to the siderite class, was found two miles southeast of Niagara, Forks county, N. D., in the early part of August, 1879, by Mr. F. Talbot, the son of the lady from whom Mr. Vennor obtained it for me. Mr. Talbot was making a collection of the various rocks and minerals in his neighborhood, and in his search for these discovered the above meteorite on the ranch owned by his father. As Mr. Talbot has since passed away, the specimen had been retained in his family rather as a keepsake in remembrance of him than as a visitor from outer space.

When I received the meteorite it weighed 115 grams and was about $30 \times 40 \times 50^{mm}$ in dimensions. It was very much oxidized, of a brownish-black color, and showed no trace of the original crust whatever. In sawing it we succeeded in getting but three sizeable pieces, as it crumbled into small fragments from 2 to 4 or 5 grams in weight in cutting. The largest piece obtained of the unoxidized iron suitable for etching weighed 26 grams and is now in the Ward-Coonley collection of meteorites. The only other piece suitable for etching weighed 17 grams and is in the British Museum collection. The largest fragment from the crumbled portion of the iron was a fairly good tetrahedron, $24 \times 23 \times 15^{mm}$ in its greatest diame-

ters, and weighed 18 grams. This fragment showed bright plates of taenite on two of its cleaved faces. This feature was likewise shown on a number of the smaller fragments.

On etching the two pieces composed of the unoxidized iron, its octahedral structure was strongly marked in the Widmanstätten figures, the kamacite plates being somewhat broad with a second series of markings of hair-like lines upon them about the size of the Neumann lines on the Braunau iron.

Mr. J. M. Davison, of the Reynolds Laboratory of the University of Rochester, kindly made the analysis of this meteorite for me, and found it to be composed of

Fe - - - - - -	92.67
Ni - - - - - -	7.37
CO - - - - - -	0.13
	100.17

Specific gravity 7.12.

From its close proximity to Niagara, we will designate the siderite the Niagara, Forks county, N. Dakota Meteorite.

H. L. Preston.

Rochester, N. Y.

ON THE SKULL OF NYCTODACTYLUS, AN UPPER CRETACEOUS PTERODACTYL.

Elsewhere I have published a brief description, with a restoration,[1] of an unusually complete specimen of *Nyctodactylus*, recently collected by my assistant, Mr. H. T. Martin, in western Kansas. At the time this restoration was made, the skull was lying in its original matrix, with its palatal surface uppermost. On account of its extreme delicacy, it was thought best then not to attempt its removal. This, however, has since been done in a most skillful manner by Mr. Martin, and it is now almost completely removed from the chalk in which it was embedded. Its delicacy and fragility may be suspected from its weight, scarcely thirty grammes, the mandible weighing about nine grammes more. The remarkable perfection and relative freedom from distortion render the specimen especially valuable for study. The mandible was displaced, in no wise obscuring other parts. The skull is of course depressed, but not so much as one might expect from the position in which it was lying, and there is a slight lateral compression to the right, but not enough to render the interpretation of the characters at all difficult. I give herewith a photographic reproduction of the back part of the skull, as it was seen before removal from the matrix. The anterior portion, on a separate block of matrix, has been omitted in order to show the hyoid bones lying partly beneath it. In the drawings I have attempted to restore the skull as nearly as possible to its living condition. There is yet a possibility that I have made the skull a little too broad, but, if so, the exaggeration must be so small as to be scarcely appreciable. The drawings were made by myself, at least insuring a careful study of the parts.

The premaxillary doubtless comprises the whole anterior portion of the beak, as in other known pterodactyls. In the middle behind, it separates the nares by a rather broad, gently convex

[1] *American Journal of Anatomy*, Vol. I, p. 297.

or laterally flattened bridge of stout bone, gradually and nearly uniformly decreasing in width posteriorly to an acute point between the frontals near the middle of the orbits. Its margins are rounded as far back as the union with the anterior processes of the frontals, which continue the same convex borders to the free margin of the orbits. The sutures separating the bone from the frontal posteriorly are indicated by lines exactly alike on the two sides, and hence evidently sutural. On the sides the union with the maxillæ is indeterminate. If this union is as in *Rhamphorhynchus*, as described by Woodward,[1] its position would be back of the anterior end of the nares. In *Scaphognathus*, however, Plieninger[2] would locate the suture at the anterior extremity of the nares. Its alveolar borders form straight, sharp, smooth ridges, with the inner wall two or three millimeters in width, meeting the palatal surface at an angle of about 135 degrees. The middle portion above is regularly rounded, forming an arc of about a third of a circle. This portion has its walls distinctly thicker than elsewhere, and has resisted compression; the sides from this median convexity seem to have been gently convex, meeting the middle convexity in a shallow groove. The surface is smooth, as in *Ornithostoma* (*Pteranodon*), without pits or depressions. As in that genus the texture of the bone of the beak has a distinct fibrillation longitudinally, sufficiently well marked to enable one to distinguish fragments from this part of the skeleton; a fact long since recognized by collectors of these animal remains in the field. I am convinced there were no pits, depressions, or conspicuous foramina on the premaxillary, and that neither in this genus nor in *Ornithostoma* was there a longitudinal ridge in the middle above. The proof of this is positive in both this genus and in *Ornithostoma*. On the under side, the bone forming the palatal surface, in part probably composed of the premaxilla, in part of the vomers, is of extreme tenuity, of the thickness of ordinary writing paper. It appears to have been gently concave through-

[1] *Ann. Mag. Nat. Hist.*, Vol. IX, No. 2, 1902.

[2] *Paleontographica*, Vol. XLI, p. 203, 1894.

out and smooth; on the sides between this bone and the roof the space was more or less filled in with a loose cancellated bone, but under the convexity of the middle there was a considerable cavity. On the under side of the premaxillary, back of the anterior ends of the nasals, are two pits or depressions, separated by a low ridge, evidently rhinencephalic fossæ.

The frontal bone is broad, unpaired, smooth, and nearly flat. Anteriorly it extends forward on either side as far as the posterior end of the nares, receiving between its two pointed processes the posterior pointed extremity of the premaxillary, as already described. There is no indication whatever of a median crest, a fact to which doubtless is due the position of the skull upon its dorsal surface, a position which I have never observed in specimens of *Ornithostoma*. Plieninger speaks of a rudimentary frontal crest in *Pterodactylus*, and its entire absence in this genus is remarkable. Posteriorly, the union with the parietal is indeterminable. On the sides it forms the horizontal, thin, superior border of the orbit for a little more than its posterior half, terminating in an angle a little before the beginning of the attachment of the postfrontal. At the anterior angle the border turns inward with a concavity looking forward, and then curves forward to be continuous with the sides of the premaxillary. The parietal, or fronto-parietal, continues the plane of the frontal in a long, U-shaped plane, forming the rounded posterior extremity of the skull. The sides of this slender U form the inner and front margin of the supratemporal fossa; from this slightly convex margin posteriorly the parietal descends downward and outward in a thin wing, articulating at the extremity with the posterior flattened end of the squamosal. This wing-like process narrows anteriorly to be continuous with the sides of the braincase.

The nasal is a slender bar of bone, beginning on the under side of the premaxillary, a little back of the middle of the nares, and extending downward and outward to unite with the ascending process of the maxilla to form the posterior boundary of the nares. Posteriorly it is a cribriform plate filling up the concave

sinus in front of the prefronto-lachrymal bone. The bone evidently continues over the outer surface of the maxillary process to unite with the lachrymal, and perhaps also with the ascending process of the malar. On the under side of the premaxillary the bones of the two sides may meet in the middle, though this seems doubtful.

The prefrontal and lachrymal cannot be distinguished from each other, and there seems to be some disagreement among writers as to which of the two elements should be called the prefrontal, were they distinguishable. The prefrontal must be that portion articulating along the sides of the premaxillary and frontal, while the lachrymal is that part which forms the anterior or anterior superior border of the orbit, either articulating directly with the frontal and the prefrontal, or with the prefrontal only, which one should expect. In the present specimen the compound element is sharply distinguishable from the frontal and premaxillary, as also the nasal. It begins on the side of the premaxilla a little back of the visible surface of the nasal, to which it is attached, as a slender pointed anterior process, and widens out posteriorly, forming a concave border, to which the thin, imperfectly ossified posterior part of the nasal attaches. Externally it widens out again into the broader horizontal plate forming the anterior superior roof of the orbit, which anteriorly curves downward to meet the jugal. Its orbital margin is thin.

The jugal bone extends forward on the outer and inferior side of the maxilla to beyond the middle of the nares. How far front it goes cannot be determined. In *Ornithostoma* the distinguishing suture, placed as in *Nyctodactylus*, seems to be continued as far forward as the anterior end of the nares, which would seem to indicate that the premaxilla does not reach as far back as in Rhamphorhynchus. At the front extremity of the orbit it sends up a slender process of bone, superimposed upon a thin expansion of the maxilla, to meet the lachrymal and nasal. Beyond this it forms a narrow bar, four or five millimeters in width, to the lower extremity of the quadrate, and then turns upward and backward a little more broadly to join, by a long

squamosal suture, the outer side of the quadrato-jugal, forming the anterior superior boundary of the lower temporal vacuity. In *Ornithostoma* it very clearly unites above with both the quadrato-jugal and postfrontal, and in all probability the same relations obtain in *Nyctodactylus*, but of this I am not sure.

The supratemporal bar is evidently formed of two bones, as in *Ornithostoma*. The superior one, joining the outer angle of the frontal (and parietal), is clearly the postfrontal or post-fronto-orbital. It extends backward to the head of the quadrate, also touching the squamosal, and probably also joining the jugal, as in *Ornithostoma*. The inferior outer part of the bar, uniting with the jugal, as described, anteriorly, the head of the quadrate, and apparently also the squamosal posteriorly, is, I suppose, the quadrato-jugal, though it corresponds precisely in position and relations with the bone I have called the prosquamosal in the mosasaurs, following Baur. This bone in these and other lacertilians has, at various times, been called the prosquamosal (Baur, Williston), the quadrato-jugal (Gegenbaur, Merriam, Baur), the squamosal (Owen, Huxley, Cope, Baur), and the supratemporal (Cope). In this pterodactyl the bone does not descend to separate the jugal from the quadrate. This, according to Seeley, is sometimes the condition among the pterodactyls. If so, the element must surely be the quadrato-jugal, and not the prosquamosal.

The squamosal seems clearly defined. It is a triangular, curved bone. A small process runs forward to join the post-frontal and "quadrato-jugal;" a broader and flat one curves downward and inward to join the wing-like squamosal process of the parietal, forming the parieto-squamosal arch, while a third joins the opisthotic (paroccipital), and probably also the head of the quadrate. It thus helps to form a small vacuity on the occipital region, between the opisthotic, parietal, and squamosal — the supraoccipital vacuity. It has nothing to do with the brain-case, as Seeley thinks it has in the European forms.[1]

The occipital condyle forms something less than a hemi-

[1] SEELEY, *Dragons of the Air*, London, 1901.

sphere, smoothly rounded, and with a small pit in its center. It seems to have looked downward and backward at an angle of about 45°, though it is possible that its angle with the horizontal plane of the skull may have been slightly greater. The basi-occipital forms a rounded, somewhat concave and roughened surface, clearly directed at a considerable angle backward. The paroccipital process is a broad, flattened bar, directed outward, backward, and somewhat upward to join the squamosal and quadrate broadly. Above them there is a small vacuity, as already described, while the outer extremity expands to join closely the inferior posterior surface of the quadrate, reaching nearly as far as their middle. The supraoccipital is directed upward and backward, joining the parietal in forming the posterior flattened prolongation of the skull. Their separation cannot be made out, but the two together form a considerable concavity looking downward and backward, with a slender median crest — the occipital crest — along the outer two-thirds.

The quadrate is more narrow above, and is firmly united with the opisthotic, squamosal, and "quadrato-jugal" above; below and to the outer side with the jugal; internally below with the pterygoid. The articular surface looks more nearly downward. The transverse axes of the two join each other at an angle of about 20°. Each has a deep oblique trochlear groove running from within outward and backward, with the stronger convexity at the inner extremity. The basi-sphenoid is an elongated, flattened, or slightly convex bone, somewhat wider in front than behind, with concave sides, and situated in the same plane with the pterygoids and palate. It joins the pterygoids at each anterior angle broadly and flatly.

The pterygoid is firmly and indistinguishably united with the quadrate at its lower inner extremity, close to the articular surface, by a broad process which ascends slightly to the plane of the palate. The two bones are separated from each other throughout their entire length, or at most touch each other by the slender tips of the anterior inner processes. Anteriorly the bone divides into two unequal processes — a slender one,

directed inwardly and anteriorly, closely approaching or touching its mate in the plane of the palate ; and a larger one, which goes forward to beyond the middle of the narial vacuity, articulating with the ectopterygoid, and distally, by a long suture, with the palatine. Between the two there is an arrow-shaped vacuity posteriorly, bounded behind by the basi-sphenoid, the indentation for the head of the arrow formed by a small, thin inner process. This form of the pterygoid, it will be seen, is quite different from that figured and described by Woodward in Rhamphorhynchus. The slender inner process does not turn upward to meet a vomer, as Woodward thinks may be the case in the skull described by him, and the processes which, in his specimen, turn inward and upward are, in *Nyctodactylus*, closely applied to the inner side of the palatines. The pterygoid does not unite with the vomer in *Nyctodactylus*.

The ectopterygoids are thin, narrow bones, articulating broadly with the outer margin of the pterygoid, and exteriorly with the inner side of the slender posterior extremity of the maxilla. The bone is directed forward and outward, its concave margins forming the anterior and posterior borders of the pterygo-jugal and posterior palatine vacuities.

The palatines are long, narrow, thin bones, articulating by a long suture on the inner side with the pterygoid, and on the outer side with the maxilla. Anteriorly the union with the maxilla or vomers is indeterminable.

The relations of the maxilla can be made out only in its posterior part. Its union with the jugal has already been indicated. Posteriorly it sends up a thin, curved process to meet the nasal, forming the posterior inferior boundary of the nares. Back of the thickened portion of this process there is a thin plate reaching back under the superior process of the jugal, the bottom of an oval depression or excavation, which clearly corresponds to the antorbital vacuity of the earlier pterodactyls. From this it is evident that the antorbital vacuity is not united with the nares in either this genus or *Ornithostoma*.

The vomer cannot be made out. If it forms a part of the

palatal surface, it is so indissolubly united with the maxillæ, palatines, and premaxillary that no signs of its union can be detected. One thing is certain, it does not separate the narial vacuities, and in all probability it does not touch the pterygoid at all.

Mandibles.—The mandibles are preserved nearly complete, their tip only being wanting—the portion which led to the detection of the specimen as it protruded from the chalk. It was lying horizontally, with the under surface uppermost, but has been entirely removed from the matrix. It has suffered a slight lateral compression to the left.

The cotylar cavity fits well on the condyles of the quadrate. The projection back of the articulation is very slight, less so than in *Ornithostoma.* The rami are slender, flattened from within outward, and are broadest at about their middle, the upper thin margin being gently convex from near the cotylus to as far forward as the symphysis, which begins about fifty millimeters in advance of the anterior end of the external nares. From the beginning of this symphysis, diminishing in width to the anterior extremity, the under margin is convex, not carinated. About twenty-five millimeters back of the true symphysis of the dentaries there is a symphysis of the thin bone which forms the floor of the mouth. This forms a thin, deeply curved hind border joining rami about midway between their upper and lower margins. The floor of the mouth from here onward seems to have been, like the opposing palatine surface, smooth, and nearly plane. The space between these surfaces, was, however, somewhat greater posteriorly than anteriorly, since the alveolar parapet is considerably deeper posteriorly. The concave posterior margin of the floor is about twenty millimeters in front of the anterior end of the internal narial vacuity. Anteriorly the margins of the mandibles are as in the upper jaws. In cross-section through the symphysis the mandible was, I think, somewhat concave or partly plane on the sides, with the under margin convex, not convex throughout, as I have thought might be the case in *Ornithostoma.* The mandible certainly could not have possessed very great strength in seizing.

Openings.—The external nares are large and ovate, looking outward and upward and forward. They are bounded above by the premaxillary anteriorly, the nasal posteriorly, below by the maxilla (and premaxillary anteriorly?), behind by the nasal above and the maxilla below.

The orbits are longer than wide, looking outward and but slightly upward and forward. The superior emargination above (doubtless roofed over in life by the integument) if not taken into account would leave the orbit oval in shape, with the anterior end rather broader than the posterior. It was bounded above by the frontal, prefrontal, and lachrymal, by the lachrymal and malar in front, the malar below and behind, and the postfrontal in part behind. It had a ring of thin, large sclerotic plates, which were preserved in displaced positions. The separate plates were not united by imbrication, as in the mosasaurs.

The supratemporal vacuity is broadly oval in shape, deep anteriorly and shallow posteriorly, bounded on the inner side by the parietal, on the outer side by the postfrontal and squamosal, and behind by the margin of the squamosal and parietal process. It opens anteriorly into the spheno-quadrate vacuity, and has a narrow slit between the squamosal and opisthotic. The infratemporal vacuity is long and narrow, broader posteriorly. It is bounded on the inner side and behind by the quadrate, externally and above by the jugal and the quadrato-jugal. The large oval vacuity between the quadrate and the basi-sphenoid is broadest at the middle, bounded in front by the quadrate process of the pterygoid, behind by the paroccepital process. The pterygo-jugal vacuity is irregular and elongated, bounded behind by the articular end of the quadrate, on the outer side by the jugal and maxilla, on the inner side by the pterygoid posteriorly and the ectopterygoid anteriorly. The posterior palatine vacuity is a small oval vacuity placed obliquely between the ectopterygoid behind, and the palatine in front, barely touching, if at all, at the extremities the pterygoid and the maxilla. The interpterygoid vacuity is arrow-shaped, placed between the basi-sphenoid posteriorly and the pterygoids on the sides. The narial vacuity

is a very large opening, oval in general shape, but with a triangular projection behind made by the two inner processes of the pterygoids, and a smaller triangular process in front extending back from the roof of the mouth. It was not divided in the middle and was doubtless covered over for the most part by membrane pierced by the internal nares.

The skull of *Nyctodactylus*, while presenting very great resemblances to that of *Ornithostoma* (*Pteranodon*) differs in important characters. Its quadrate is much shorter, terminating below in the condyle for the mandible nearly below the middle of the orbit, while in *Ornithostoma* the articulation is in advance of the orbit. The orbit and supratemporal vacuities are proportionally larger, and there is no crest, not even a rudimentary one. The bar between the orbit and the nares is narrower, the frontal bone less broad relatively in *Ornithostoma*.

In *Nyctodactylus* we have a less highly specialized type of pterodactyl than is seen in *Ornithostoma* as is evidenced by the absence of the crest, the plane frontal bone, and the less oblique position of the quadrate. On the other hand the genus has the same type of skull, and toothless jaws, and the general proportions of the skeleton throughout are the same. I believe that the resemblances between the two genera are of much greater importance than the differenees. These differences rest in the non-articulation of the scapula with the supraneural plate of the vertebræ, in the absence of crest, and the position of the quadrate especially. Both forms are toothless. If much importance is given to the scapular articulation the two genera must go into different families at least — *Ornithostoma* among the Ornithocheiridæ, and *Nyctodactylus* with the Pterodactylidæ. But such a severance is, I, believe, questionable. It is a rather curious instance of parallel growth that has brought about the toothless forms of *Ornithostoma* from the toothed *Ornithocheirus*, and the toothless *Nyctodactylus* from the toothed *Pterodactylus*; possibly this has been the phylogeny. On the other hand, it would also seem possible that the same toothless form has been ancestral to both

Nyctodactylus, the lesser, and *Ornithostoma*, the more, specialized type.

If my interpretation of the elements of the skull of *Nyctodactylus* is correct, I fail to see any marked avian resemblances in it. The only character that might be considered as such is the undivided narial vacuity, aside from the lightness of the bones and their closely united sutures, both adaptive characters. The supratemporal arch is purely reptilian, as is the presence of the ectopterygoid, etc. The union of the premaxillary with the frontal is found in the plesiosaurs. A further discussion of this question I hope to present in a future paper, in which I shall give a more detailed description of the remainder of the skeleton, with illustrations.

I am convinced that the arrangement of the ribs back of the sternum, not only in *Nyctodactylus*, but in other pterodactyls, is different from what has been generally supposed and figured. They extended outward in the plane of the wing membrane, which they served in a measure to support, and did not enclose the ventral cavity. From a recent examination of the type of *Rhamphorrhynchus phyllurus* Marsh, I am satisfied that this was their function in that animal, and I doubt not it was also in all other pterodactyls. This difference in function accounts satisfactorily for the marked contrast in slenderness between the anterior and posterior ribs, as also for the slight curvature of the latter.

The hyoid bones of the present specimen are quite like those of other pterodactyls — long, slender rods. They are shown in part in Plate I. At the back of the skull in the same plate is also seen a small triangular or V-shaped bone, which I take to be the proatlas.

It will be of interest to note that in the matrix underlying the skull occurred several specimens of the Cirriped *Stramentum*, together with a vivid impression of a Lepas-like barnacle having a slender, flexible, naked peduncle about 40^{mm} in length. The capitulum seems to have been enclosed either in chitinous or membranous plates, evidences of which are present, and impres-

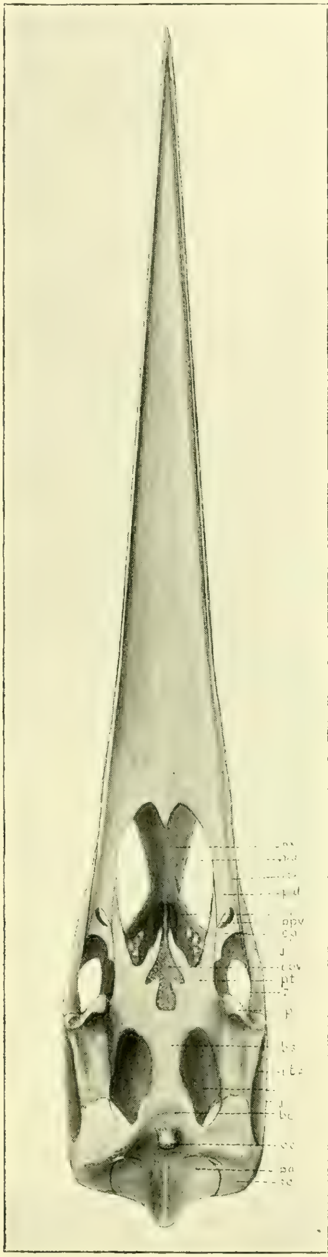


Fig. 1.

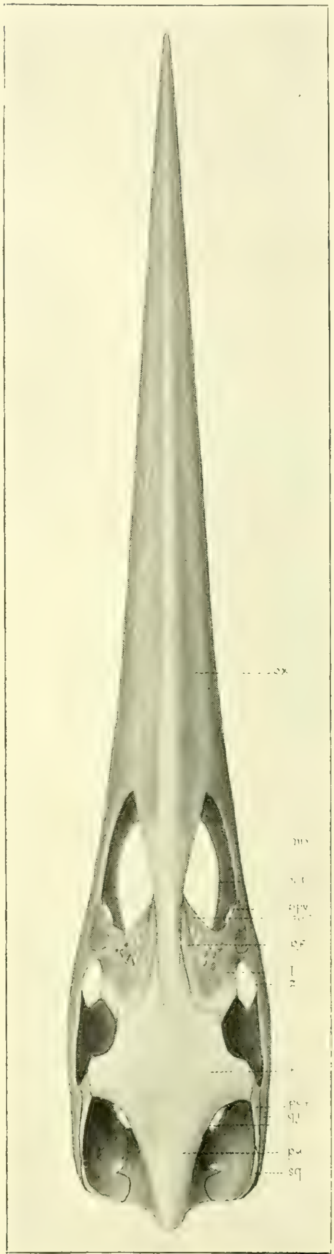


Fig. 2.

sions of the cirri are plainly present. Other impressions of phyllopods or ostracods are also abundant in the matrix.

S. W. WILLISTON.

UNIVERSITY OF KANSAS,
Lawrence, April, 1902.

EXPLANATION OF PLATES.

PLATE I. Under surface of posterior part of skull, lying in the matrix slightly enlarged. Near the anterior end are seen the two hyoid bones, and in the occipital region, the small, triangular proatlas.

PLATE II. Fig. 1, Under view of skull; Fig. 2, upper view of same, both a little more than half natural size; *bo*, basi-occipital; *ep*, ectopterygoid; *fr*, frontal; *ipv*, interpterygoid vacuity; *itv*, infratemporal vacuity; *j*, jugal; *l*, lachrymal; *mx*, maxilla; *na*, nares; *nas*, nasal; *oc*, occipital condyle; *pa*, parietal; *pal*, palatine; *pf*, prefrontal; *pof*, postfrontal; *ppv*, posterior palatine vacuity; *px*, premaxillary; *q*, quadrate; *qj*, quadrato-jugal; *sq*, squamosal; *z*, pterygo-jugal vacuity.

CROTALOCRINUS CORA (HALL).

AMONG the internal casts of crinoids which occur commonly in the dolomitic Niagaran limestone of northeastern Illinois and southeastern Wisconsin, is a species which was first described by Hall in 1868 under the name *Cyathocrinus cora*. The cotypes of this species, two in number, are recorded from Racine, Wis., and are now preserved in the collections of the American Museum of Natural History in New York. Specimens very much larger than these types frequently occur in the dolomite near Chicago, but they resemble them in all essential characters and all are undoubtedly specifically identical.

The body of this crinoid is more or less subglobular in form, with a large column, and has been but rarely found preserved in any condition other than as internal casts. The plates composing the body are arranged essentially as in members of the genus Cyathocrinus. There are five large underbasals which support five large basals, four of which are hexagonal in outline, the fifth being heptagonal by reason of the truncation of the distal angle for the support of a single subquadrangular anal plate. The radials are large, wider than high, and are in contact laterally, except the two posterior ones, which are separated by the large anal plate. Until the discovery of the specimen illustrated in the present paper, the plates above the radials have never been observed, or at least they have never been recognized as belonging to this species.

In 1900 a single imperfect radial plate of a crinoid, with brachial plates attached, was recognized by Weller as representing the genus Crotalocrinus, and was described under the name *C. americanus*. This specimen is a natural mold of the exterior, and was found associated with *Cyathocrinus cora*, but there was no evidence by which the two forms could be correlated.

There has recently come into the possession of the Walker

Museum, through the generosity of Mr. G. F. Harris, of Chicago, a specimen of the so-called *Cyathocrinus cora*, upon which nearly all of the plates of the calyx are preserved, as well as some of the brachial plates. This specimen demonstrates that the type of *Crotalocrinus americanus* is nothing more than a radial plate with brachials attached of the so-called *Cyathocrinus cora*, and that the latter species must be transferred from the genus Cyathocrinus into Crotalocrinus. This remarkable genus of crinoids, therefore, which has hitherto been considered as such a rarity in the Niagaran fauna of America, proves to be one of the common members of the fauna of this age in Illinois and Wisconsin. It is of especial interest because it is one of those peculiar forms which relates the Niagaran faunas of the interior of North America, so closely with the faunas of Gotland and England.

This American species of Crotalocrinus is most closely allied to *C. rugosus* Miller, *var.*, from Gotland, as illustrated by Angelin.[1] Both have the same subglobular form of calyx, constricted at the top of the radial plates, and both have the same style of surface markings, consisting of shallow furrows which cross the sutures dividing the plates at right angles. In the American specimens these markings are so pronounced as to be usually discernable even on internal casts. The arrangement of the fixed brachial plates in the two species, however, is quite different, if Angelin's illustrations can be depended upon.

In the arm plates of Crotalocrinus the axial canals are a conspicuous feature. In converging toward the base of the arm, these canals unite into a single trunk which pierces the radial plate. The axial canals are well shown in both the specimens preserving the brachial plates, and the casts of the canals are frequently more or less well preserved in the internal casts of the species as it is ordinarily preserved.

The species which has been described as *Cyathocrinus vanhornei* S. A. M. is probably another member of the genus Crotalocrinus. It is known only from internal casts, but these speci-

[1] *Iconog. Crin.*, Plate 17, Figs. 8, 8a.

mens usually preserve the cast of the basal portion of the axial canal where it enters the radial plate. The species differs from *C. cora*, especially in the strong constriction of the calyx at its middle line.

In the light of the observations here recorded, the synonomy of *Crotalocrinus cora* will stand as follows :

Crotalocrinus cora (Hall).

1868. *Cyathocrinus cora* Hall, *Twentieth Rep. N. Y. State Cab. Nat. Hist.*, p. 324, Pl. XI, Figs. 13, 14.

1870. *Cyathocrinus cora* Hall *Twentieth Rep. N. Y. State Cab. Nat. Hist.* (Rev. Ed.), p. 366, Pl. XI, Figs. 13, 14.

1879. *Cyathocrinus cora* W. & S., *Rev. Palæocr.*, Pt. I, p. 85.

1881. *Cyathocrinus cora* S. A. M., *Jour. Cinn. Soc. Nat. Hist.*, Vol. IV, p. 171.

1900. *Cyathocrinus cora* Weller, *Bull. No. 4 Nat. Hist. Surv., Chicago Acad. Sci.*, p. 62, Pl. XIV, Figs. 6–10.

1900. *Crotalocrinus americanus* Weller, *Bull. No. 4, Nat. Hist. Surv., Chicago Acad. Sci.*, p. 143, Pl. XIV, Fig. 1.

EXPLANATION OF PLATE.

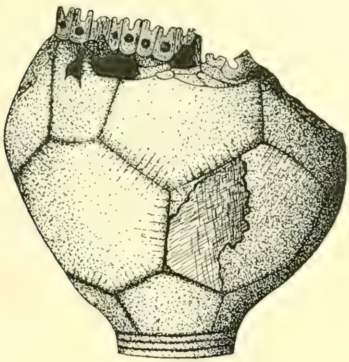
FIG. 1.—A nearly perfect specimen of the calyx of *Crotalocrinus cora* showing the plates of the calyx with some of the brachial plates.

FIG. 2.—An internal cast of *Crotalocrinus cora*, showing the broken bases of the casts of the axial canals where they pierce the radial plates.

FIG. 3.—An outline of the specimen which was made the type of *Crotalocrinus americanus*, showing the arrangement of the fixed brachial plates in *Crotalocrinus cora.*

FIGS. 4–5.—The casts of two radial plates of *Crotalocrinus cora*, preserving the internal casts of the axial canals.

STUART WELLER.



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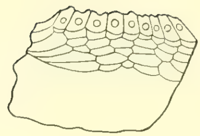

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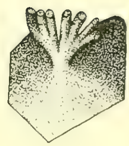

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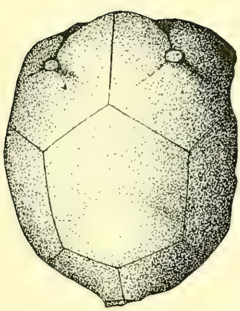

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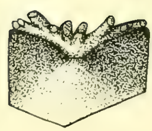

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THE CARBONIFEROUS FISH-FAUNA OF MAZON CREEK, ILLINOIS.

Of the thousands of fossiliferous ironstone nodules of Coal Measure age, occurring at Mazon Creek, near Morris, in Grundy county, Illinois, only a small percentage afford indications of vertebrate remains, and these consist principally of detached fish-scales. Occasionally, however, complete individuals of fossil fishes, and still more rarely, amphibian skeletons have been brought to light, but all told the number of even tolerably perfect specimens preserved in different museums is very insignificant. Probably the two finest series of Mazon Creek nodules ever brought together are the Lacoe collection, belonging to the United States National Museum in Washington, and the Strong collection, purchased by the late Professor Marsh for the Peabody Museum, at Yale College. Shortly before the decease of Professor Marsh, nearly all of the fossil fishes in the Strong collection were placed by that gentleman in the hands of the writer for study and description; and more recently some further material has been loaned for the same purpose by Professor C. E. Beecher, to whom grateful acknowledgments are due.

Mazon Creek fish-scales have been exhaustively studied by E. D. Cope[1] and O. P. Hay,[2] and the latter has also described a nearly perfect example of a Palæoniscid fish, named by him *Elonichthys hypsilepis*. A few other Palæoniscids and Platysomids have been described by Cope[3] and by Newberry and Worthen;[4] and two Acanthodian species have recently been made known by the present writer.[5] These citations complete the literature references on Mazon Creek fishes. In the following paragraphs

[1] *Proc. Amer. Phil. Soc.*, Vol. XXXVI (1897), pp. 71–82.

[2] *Ibid.*, Vol. XXXIX (1900), pp. 96–120.

[3] *Proc. U. S. Nat. Museum*, Vol. XIV (1891), p. 462.

[4] *Pal. Illinois*, Vol. II (1866), and Vol. IV (1870).

[5] *Bull. Mus. Comp. Zool.*, Vol. XXXIX (1902), pp. 93, 94.

brief descriptions are given of two species of *Acanthodes*, and one each of *Cœlacanthus* and *Elonichthys*, with a list of the known vertebrate fauna occurring at this locality.

GENUS ACANTHODES, AGASSIZ.

Representatives of the Acanthodii are extremely rare in the Palæozoic rocks of North America. If we neglect the detached spines of *Machæracanthus*, and the indeterminable mass of scales described by J. M. Clarke as *Acanthodes pristis*,[1] American Acanthodians are limited to but three species of *Acanthodes* and one of *Mesacanthus*. Of these *Acanthodesconcinnus* Whiteaves and *Mesacanthus affinis* (Whiteaves) occur in the Upper Devonian of Scaumenac Bay, Canada, and the recently described *Acanthodes marshi* and *A beecheri* are from the Mazon Creek locality, in Illinois.

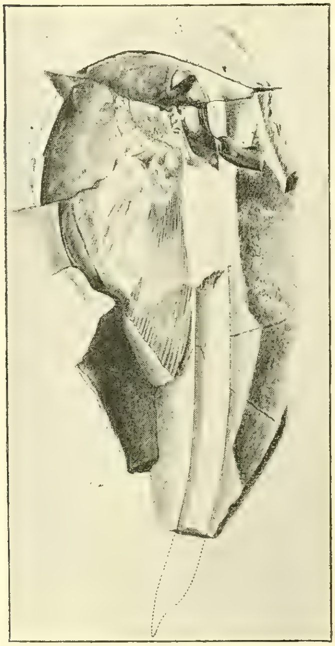

FIG. 1.—*Acanthodes marshi* Eastm. Coal-measures, Mazon Creek, Ill. Pectoral fin with associated actiontrichia and fin-spine. $\times\frac{3}{4}$.

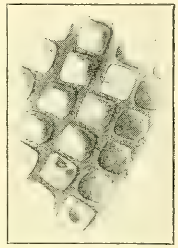

FIG. 1*a*.—Shagreen granules of *A. marshi*. $\times\frac{4}{1}$.

Acanthodes marshi Eastman.

This species is remarkable for being one of the largest, as, on the other hand, *A. beecheri* is one of the smallest known *Acanthodians*. In *A. marshi*, not only are the shagreen granules much coarser than those of *A. bronni* and *A. wardi*, which are the largest of European species, but the fin-spines are considerably longer and stouter, averaging about 9^{cm} long, and from .5 to .8^{cm}

[1] *Bull. U. S. Geol. Surv.*, No. 16 (1885), p. 42.

wide. In Fig. 1 is shown a very interesting pectoral fin preserved in counterpart, and retaining the actinotrichia in natural association with the spine. The fibrous rays are quite long and numerous as compared with those of other species, and extend well up toward the point of insertion of the spine. There is no trace here, unfortunately, of a basal cartilage abutting against the proximal end of the spine, nor does this specimen display any of the dermal granules with which the fin-membrane was stiffened, although such are exhibited by a smaller specimen belonging to the Yale Museum. The scales of *A. marshi* are in

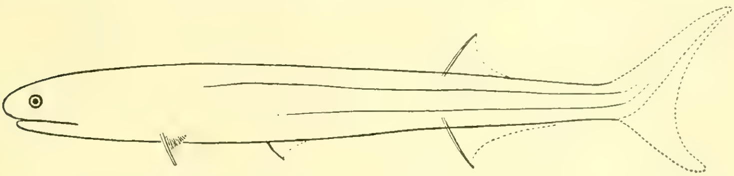

FIG. 2.—*Acanthodes beecheri* Eastm. Coal-measures, Mazon Creek, Ill. Restoration showing outline of body and position of fins. $\times \frac{2}{1}$.

the form of shagreen granules, averaging about one square millimeter in size, smooth and polished externally, and gently convex or rounded on both the outer and attached surfaces. (Fig. 1*a*). The internal structure consists of fine layers of dentine arranged in quadrate fashion about a small central pulp-cavity. The best account of the microscopic structure of Acanthodian and Thelodus-like scales is that given by Rohon about nine years ago.[1]

Acanthodes beecheri Eastman.

Description. — A very small species, attaining an extreme length of about 5.5^{cm}. Body elongated and slender, the maximum depth being contained about nine times in the total length. Pectoral spines not much stouter or longer than the others; pelvic fins small, slightly nearer the pectorals than the anal; anal fin slightly larger than the dorsal, which is placed immediately behind. Length of dorsal and anal spines greater than maximum depth of trunk. Caudal lobe remarkably elongate. Scales extremely minute.

This species is represented by two nearly complete individuals preserved in counterpart and belonging to the Yale Museum,

[1] *Mem. Acad. Imp. Sci. St. Petersbram,* Vol. XLI (1893), No. 5, p. 22.

neither of which, however, exhibits the caudal region satisfactorily, nor are the heads well preserved. Only the dorsal and anal fin-spines are displayed by the larger specimen; but in the smaller all the fin-spines are preserved, although the dorsal is slightly displaced and the distal ends of the pectorals are wanting. The accompanying figure, based on both specimens, is of composite nature, and represents the general outline and proportions of the fins, the restored parts being indicated in dotted lines.

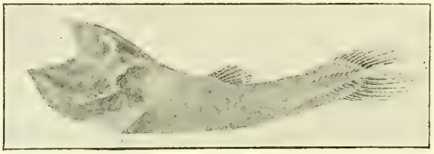

FIG.—3. *Cœlacanthus exiguus*, sp. nov. Coal-measures, Mazon Creek, Ill. Complete individual, lacking posterior dorsal and anal fins. $\times\frac{2}{1}$.

GENUS CŒLACANTHUS, AGASSIZ.

J. S. Newberry records having received from Mazon Creek "a single specimen each of *Eurylepis* and *Cœlacanthus*, probably not distinct from those found at Linton, Ohio." No examples of the former genus have come under the writer's observation, but ornamented scales and head-plates referable to *Cœlacanthus* sometimes occur in Mazon Creek nodules, and very rarely there are found complete fishes of small size, evidently quite distinct from other described species. In most specimens the posterior dorsal, anal, and pectoral fins are lacking, and it seemed at first sight as if the second dorsal had become lost through specialization. One individual, however, shows it very distinctly, and the absence of this and the anal in the remaining examples is to be attributed to faulty preservation.

Cœlacanthus exiguus, sp. nov.

Description.—A small species, attaining a maximum length of about 4.5^{cm}. Trunk narrow and elongated, the head occupying about one-fourth of the total length. First dorsal consisting of relatively few stout rays, and situated slightly in advance of the pelvic pair; second dorsal midway between the first dorsal and principal caudal; the latter comprising nine stout rays above and below. [Scale-structure and ornamentation of head-bones not observed.]

This species is represented by ten specimens in the Yale, and one in the Harvard Museum, most of them being only about 3^{cm} long, and very deficient in preservation. They agree in having a narrow, gradually tapering body, which terminates in an equilobate caudal fin, with indications that the axis was prolonged into a supplementary caudal. The first dorsal and caudal, owing to their stronger attachment, are present in nearly all specimens, but the remaining fins have in most cases become destroyed. The first dorsal has usually seven or eight stout rays, and is situated near the middle of the trunk. Ten long, hollow rays are to be counted in the single specimen displaying the posterior dorsal, and nine above and below in the symmetrical caudal. The neural and hæmal spines are very long in the abdominal and caudal regions. The ossifications of the axial skeleton are continued nearly to the termination of the principal caudal. The squamation must have been exceedingly delicate, as no indications of scales are to be observed in any of the specimens, nor do any of them have the cranial elements satisfactorily preserved.

FIG. 4.—*Elonichthys perpennatus*, sp. nov. Coal-measures, Mazon Creek, Ill. Complete individual, the distal portions of median fins not fully shown. $\times \frac{2}{1}$.

GENUS ELONICHTHYS, GIEBEL.

Two closely related species are already known from Mazon Creek, *E. peltigerus* Newberry, and *E. hypsilepis* Hay. A study of the type-specimen of Newberry and Worthen's so-called "*Amblypterus macropterus*," now preserved in the Yale museum, leaves no doubt that this is only a mutilated individual of *E. peltigerus*. The type of the following new species is preserved in the Museum of Comparative Zoölogy.

Elonichthys perpennatus, sp. nov.

Description.—A very small species, having a total length of about 2.5^{cm}, of which the head occupies a little less than one-fourth. Fins extremely well

developed, the pectorals unusually long, and anal much extended; fulcra minute. Scales relatively small, obliquely striated; dorsal ridge-scales enlarged.

Only one individual is at present known of this interesting little form, which is shown in Fig. 4. The head is poorly preserved, and the distal extremities of nearly all the fins are either broken away or obscured by matrix. Nevertheless, sufficient characters remain for the recognition of this as a distinct species of *Elonichthys*, its chief peculiarity consisting in the remarkable development of all the fins. The pectorals are fully one-fourth the total length, and the anal has a more extended base-line than in any other species of the genus. The dorsal appears to have been high and acuminate, but is largely concealed by matrix. The caudal is also unfavorably exposed, and flexed out parallel with the main axis; but it is plain that the upper lobe was much prolonged, and covered with very large, striated ridge-scales. The dorsal-fin rays appear to have been widely jointed; the articulations of the other fins are not clearly recognizable. The dermal rays of the anal and lower lobe of the caudal are directly supported by the large hæmal spines, which are firmly united with their arches. The squamation is nowhere well preserved, but is best indicated in the anterior part of the trunk. The cranial structure does not admit of particular description. Appearances suggest that the specimen here described is an immature individual, differing however, from other known species.

LIST OF CARBONIFEROUS VERTEBRATES OCCURRING AT MAZON CREEK, ILLINOIS.

ELASMOBRANCHII.

1. *Pleuracanthus* (*Diplodus*) *compressus* Newb. (Occurs also in Ohio and Indiana.)
2. *Pleuracanthus* (*Diplodus*) *latus* Newb. (Occurs also in Ohio and Indiana.)
3. *Pleuracanthus* (*Diplodus*) *lucasi* Hay.
4. *Acanthodes beecheri* Eastm.
5. *Acanthodes marshi* Eastm.
6. *Campodus scitulus* (St. J. and W.).

DIPNOI.

7. *Ctenodus* sp. indes.
8. *Sagenodus foliatus* Cope.[1]
9. *Sagenodus lacovianus* Cope.[1]
10. *Sagenodus occidentalis* (Newb. and W.).[1] (Occurs also at Linton, Ohio.)
11. *Sagenodus quadratus* (Newb.).[1] (Occurs also at Linton, Ohio.)
12. *Sagenodus quincunciatus* Cope.[1]
13. *Sagenodus reticulatus* (Newb. and W.).[1]
14. *Sagenodus textilis* Hay.[1]

[1] Founded on scales.

CROSSOPTERYGII.

15. *Rhizodopsis* (?) *mazonius* Hay.[1]
16. *Cœlacanthus exiguus* nobis.
17. *Cœlacanthus robustus* Newb.[1] (Occurs also at Linton, Ohio.)

ACTINOPTERYGII.

18. *Eurylepis* sp. indet. (*fide* J. S. Newberry).
19. *Rhadinichthys gracilis* (Newb. and W.).
20. *Elonichthys hypsilepis* Hay.
21. *Elonichthys peltigerus* Newb.[2] (Occurs also at Linton, Ohio.)
22. *Elonichthys perpennatus* nobis.
23. *Platysomus circularis* Newb. and W.
24. *Platysomus lacovianus* Cope.
25. *Platysomus orbicularis* Newb. and W.

AMPHIBIA.

26. *Amphibamus grandiceps* Cope.

[1] Founded on scales.

[2] Including the so-called "*Amblypterus macropterus*" Newb. and Worthen.

C. R. EASTMAN.

Reviews.

SUMMARIES OF THE LITERATURE OF STRUCTURAL MATERIALS. II.

Edwin C. Eckel.

Berkey, C. P. *Origin and Distribution of Minnesota Clays.* Amer. Geologist, Vol. XXIX, pp. 171–177, March, 1902.

Residual clays, derived either from feldspathic rocks or from limestones, are of slight importance in Minnesota. The larger clay working establishments of the state are using shales, stream deposits, or glacial lake clays; the smaller brick plants of local importance use till or loess.

The shales of most importance are those of the Ordovician and Cretaceous. The Ordovician shales are found only in the southeastern portion of the state. Most beds are too calcareous for use, but one company in Minneapolis utilizes Ordovician shales in the manufacture of an exceptionally fine line of front and pressed brick. The Cretaceous shales are used in the manufacture of stoneware at Red Wing.

The clays may be divided as to origin into glacial till, glacial lake clays, glacial stream deposits, recent alluvial deposits, and wind deposits.

Locally the till includes clay deposits of workable size. These clays differ in character according to the drift in which they are inclosed. The "gray drift" which has been brought by ice movements from the north and northwest carried fine-grained, calcareous, light-burning clays, though in places weathering may have removed enough lime to give red-burning clays. The "red drift" brought in from the north and northwest carries coarser grained clays with an excess of iron, which consequently burn red.

Glacial lake clays, laid down in quiet water in interglacial periods, are confined to the eastern border of the state, where extensive deposits occur and are worked on a large scale.

Glacial stream deposits include the river silts deposited during the withdrawal of the ice. Clays of this type are worked on the Mississippi river between Minneapolis and Little Falls, and on the Missouri river between Shakopee and New Ulm. These clays are obtained from the terraces bordering the present river channels, and burn cream or gray. They are the most important of the Minnesota clays, large plants using them being located at Chaska and Minneapolis.

Recent alluvial deposits occur in the same areas as the last class and in many cases cannot be differentiated from them.

Most of the smaller brick plants of the state work on material obtained from loess deposits. The clayey loams of this class are widely distributed, but are nowhere of great thickness or value.

BLATCHLEY, W. S., AND ASHLEY, G. H. *The Lakes of Northern Indiana and their Associated Marl Deposits.* Twenty-fifth Ann. Rept. Indiana Dept. Geology and Natural Resources. Pp. 31–321, Pls. 1 and 6–12, Figs. 1–70, 1901.

The origin and uses of marl are first discussed, issue being taken with C. A. Davis on some points connected with the importance of Characae in the formation of marl deposits. The marl deposits of the state are then discussed separately in great detail.

Marl deposits of sufficient size to justify the erection of cement plants occur in Indiana only in the three northern tiers of counties. Areally, the largest of these deposits is in Lake Wawasee, which contains about 1,700 acres, while the maximum thickness (45 feet) is reported from Turkey Lake, Lagrange co. A deposit of marl equal to one covering 160 acres, ten feet thick, will supply for thirty years a plant with a capacity of 500 barrels per day· Deposits of such size are termed "workable deposits" in the present report. Thirty-two such deposits were found and are described and mapped in detail. A number of other deposits are described which, though of sufficient size, have the larger part of their area covered by ten feet or more of water and are therefore not at present workable. Improved appliances for raising marl from beneath such depths of water would render these deposits available.

BLATCHLEY, W. S. *Portland Cement.* Twenty-fifth Ann. Rept. Indiana Dept. Geology and Natural Resources. Pp. 1–30, Pls. 2–5, 1901.

A summary of the history, uses, composition, manufacture, and testing of Portland cement is followed by a brief history of the industry in Indiana.

Portland cement was first manufactured in Indiana at South Bend in 1877, from marl and clay burned in dome kilns. Operated with varying fortune, this plant was shut down finally in 1898. Two plants, also using marl and clay, but burning the mixture in rotary kilns, commenced operations in 1900, and at the time of report three additional plants were in prospect.

CUMMINGS, URIAH. [*Production of*] *American Rock Cement* [*in the U. S. during 1899*]. Twenty-first Ann. Rept. U. S. Geol. Surv., Pt. VI continued, pp. 407–411, 1901.

Résumé of the condition of the American natural cement industry during 1899, with statistics of production. Analyses and tests are quoted of a Portland cement manufactured at Chattanooga, Tenn., by burning a natural rock without admixture.

ECKEL, E. C. *The Portland Cement Industry in New York.* Engineering News, Vol. XLV, pp. 365–367, 1901.

Résumé of early history of Portland cement manufacture in New York, with descriptions of the six plants operating in 1900, and notes on the technology.

Until recently most New York plants used a mixture of marl and clay, burned in dome kilns. At present, however, the use of rotary kilns, operating on mixtures of hard limestone and clay, is increasing rapidly, half the plants in operation in 1900 being of this type.

Slag Cement Manufacture in Alabama. Eng. News, Vol. XLVII, pp. 1–62, 1902.

Description of two slag cement plants operating in Alabama, with notes on technology of slag cement in general.

The Classification of the Crystalline Cements. Amer. Geologist, Vol. XXIX, pp. 146–154, March, 1902. Reprinted in Cement, Vol. III, pp. 109–114, May, 1902. Reprinted in part in Engineering News, Vol. XLVI, p. 354, May 1, 1902.

A classification of cementing materials, with notes on raw materials, technology, and the properties of the various products. The grouping offered is as follows:

I. *Simple cements;* including those materials which are produced by the expulsion of a liquid or gas from the raw material; and whose set is due to the simple reabsorption of the same liquid or gas and a reassumption of original composition.

I*a*. *Hydrate cements;* set due to reabsorption of water. Plaster-of-Paris, cement plasters, Keene's cement, Parian cement, etc.

I*b*. *Carbonate cements;* set due to reabsorption of carbon dioxide. Limes, magnesian limes, etc.

II. *Complex cements;* including those cementing materials whose set is due to the formation of new compounds during manufacture or use.

II*a*. *Silicate cements;* set due to the formation of silicates. Hydraulic limes, natural cements, Portland cement, pozzuolanic cements.

II*b*. *Oxychloride cements;* set due to the formation of oxychlorides. Sorel stone, etc.

FREAR, WILLIAM, *The Use of Lime upon Pennsylvania Soils.* Bulletin 61, Pa. Dept. Agriculture. 170 pp., 1900.

Principally a discussion of lime in its relation to agriculture, but contains also very satisfactory accounts of limestones (in general) and lime-burning, with 273 analyses of Pennsylvania limestones, mostly compiled from reports of the Second Geological Survey of that state.

HARRIS, G. D., and VEATCH, A. C. *General Geology* (*of Louisiana*). Geological Survey of Louisiana, Report for 1899. Pp. 55–138, Pls. 1–11, Figs. 2–5, geological maps.

Report on the stratigraphic and economic geology of the state. The matter of clays, limestones, sandstones, and gravels (pp. 127–132) is here summarized.

Good brick clays are common in the alluvium and yellow loam, and are also found at several places in the hill-lands. The Eocene clays commonly lack plasticity, though some beds occur which will make a fair quality of earthenware. Good potter's clay occurs in the Lignitic, near Robeline, where it has been utilized. The clays of the Grand Gulf hills seem to be more promising than any others in the state, good exposures occurring in Catahoula and Vernon parishes.

The sandstones of the state are of two classes; the ferruginous sandstones of the Eocene and Lafayette, and the siliceous sandstones of the Grand Gulf. The former are widely distributed, but are unimportant as structural materials. The siliceous Grand Gulf sandstones are of greater value, and have been used for jetty work and railroad ballast.

Limestones of Cretaceous age outcrop at Winnfield, Coochie Brake, and Bayou Chicot. The first is a pure limestone, which may be used for lime, but not for building stone. The other two are of greater value for structural purposes. Limestone concretions occurring in the Tertiary are of local importance for lime or road metal.

The gravels of the Lafayette are rather extensively used as road metal and railroad ballast.

HILLEBRAND, W. F. *Some Principles and Methods of Rock Analysis.* Bull. 176, U. S. Geol. Surv. 8vo. Pp. 115, Figs. 15, 1900.

Detailed discussion of the methods to be followed in analyses of the silicate rocks. Stress is laid on the importance of complete and thorough analyses, and the chemist is warned against neglect to determine elements (such as strontium, barium, vanadium, etc.), often disregarded as unimportant.

HOPKINS, T. C. *Clays and Clay Industries of Pennsylvania.* III, *Clays of the Great Valley and South Mountain Areas.* Appendix to the Ann. Rept. Pa. State College for 1889–1900. 8vo, pp. 45, 1900.

Over half the paper is taken up with a discussion of the white clays of the Great Valley; the remainder containing short chapters on respectively the red brick, paving brick, and tile industries; with a brief account of the economic products, other than clays, of southeastern Pennsylvania.

The most valuable clay deposits in southeastern Pennsylvania are those occurring in the Cambro-Silurian areas of the Great Valley and South Mountains. These clays are typically white; commonly bluish-white to gray on fresh exposures, but soon weathering pure white. Closely associated with the white clays are others stained more or less by iron oxide, and being therefore yellow to brown in color. The white clays are invariably high in silica, and low in alumina. Their iron content is also low, but the alkalies are always too high to give refractory material. Genetically, the white clays are direct decomposition products of light-colored hydromica slates which occur interbedded with other Cambro-Ordivician rocks. In certain openings the clays are shown grading into the undecomposed slates. They were originally intercalated beds in a series of quartzites, limestones, etc.; but on the weathering of the rocks the clay derived from the disintegrated slates crept down hillsides, filled cavities in the other rocks, etc.—so that now the deposits are somewhat irregular, lenticular masses of varying extent. At present the clays are largely used in the manufacture of paper, and to a less extent for white tiles, and white and enameled brick.

Red building brick is made, in the Great Valley, from residual limestone clays, residual shale clays, and alluvial deposits. Of these classes the first is the most important. The clays residual from limestone make good brick, though often carrying numerous fragments of limestone, quartz, etc.

Vitrified brick is manufactured at six plants. Three of these use Triassic shale; one, Hudson River shale; while the remaining two use shales from the Cambro-Ordovician series.

Ornamental brick and tile are manufactured at several plants, various materials being in use, including clays, slates, etc.

IHLSENG, MAGNUS C. *The Road-Making Materials of Pennsylvania.* Bulletin 69, Pa. Dept. Agriculture. Pp. 104, Figs. 1–17, relief map, colored geologic map, 1900.

General discussion of road materials, their qualities, and testing; influence of topography on road construction; methods of constructing and repairing roads, etc.

Scattered notes on various Pennsylvania road materials, with a section on the distribution, by counties, of such materials.

LEWIS, F. H. *Hydraulic Cement Industry in the United States in 1899.* Mineral Industry, Vol. VIII, pp. 84, 85, 1900.

Résumé of progress in the American cement industry during 1899.

Cement Industry in the United States in 1900. Mineral Industry, Vol. IX, pp. 77–82, 1901.

Résumé of the conditions of the American Portland cement industry during 1900—a year marked by overproduction and low prices.

LEWIS, F. H., NEWBERRY, S. B., and others. *The Cement Industry.* 8vo. Pp. 235, Figs. 152. New York, 1900.

A collection of articles reprinted from issues of the Engineering Record. Detailed descriptions of a number of American cement plants, with sketches of the condition of the cement industry in various European countries; and separate chapters on the general technology of Portland cement (NEWBERRY) and the rotary kiln process (LEWIS).

MERRILL, G. P. *Guide to the Study of the Collections in the Section of Applied Geology; the Non-metallic Minerals.* Rept. U. S. Nat. Mus. for 1899. Pp. 155–483, Pls. 1–30, 1901.

Comment.—The material contained in this handbook cannot well be summarized. The sections of interest in the present connection are those on quartz (p. 215); flint (216); limestones, mortars, and cements (pp. 264–270); dolomite (p. 274); magnesite (p. 275); feldspars (p. 281); clays (pp. 325–353); gypsum (pp. 406–411); and road-making materials (p. 482). The treatment of these subjects is, in general, excellent, that of clays being eminently so. The discussion of the cements, particularly Portland, is less satisfactory.

NEWBERRY, S. B. [*Production of*] *Portland Cement* [*in the United States during 1899*]. Twenty-first Ann. Rept. U. S. Geol. Surv., Pt. VI continued. Pp. 393–406, 1901.

Résumé of the conditlon of the American Portland cement industry during 1899, with statistics of production. The method of calculating the proportions of the ingredients in a Portland cement mixture is discussed and exemplified.

RIES, HEINRICH. *Clays of New York.* Bulletin 35, New York State Museum. 8vo, pp. 455, Pls. 140, map, 1900.

Detailed discussion of the origin, properties, testing and uses of clays, and manufacture of clay products; with descriptions of the clay deposits of New York and of the industries based on them. The section on the geologic distribution of clays in New York (pp. 275–311) is here summarized, together with the sections on shales (pp. 825–841) and feldspar and quartz (pp. 841–844).

Small deposits of residual clay, of little or no economic importance, have been found at various points in Dutchess county.

The sedimentary clays are numerous and important, representing three geologic periods — Quaternary, Tertiary and Cretaceous. The latter two occur only on Long and Staten Islands, all the clays of the mainland being Quaternary.

Local basin-shaped deposits of Quaternary clays occur at many points in the central, western and southwestern portions of the state. These deposits are doubtless on the sites of former ponds, formed commonly by the damming of valleys, and later filled with the sediment of streams from the retreating ice sheet. A number of these deposits are of economic importance, and some are now worked.

The most important and extensive clay deposits in the state, however, are those in the Hudson valley. The Quaternary deposits here are of two types (1) estuary deposits of fine stratified sand and blue and yellow clays; (2) cross bedded delta deposits of coarser material. The clay is usually blue, weathered yellow where exposed. It is markedly stratified horizontally, the layers of clay being separated by extremely thin laminæ of sand. At many localities the clay is overlain by the delta deposits of rivers tributary to the Hudson. The Quaternary history of the region is summed up as follows: During the retreat of the ice sheet from the Hudson valley the glacial streams deposited as kames a great amount of ground up material, principally shale. Subsequent to the retreat there was a depression of the land amounting to 80 feet at New York city and 360 feet near Schenectady. During this depression a great amount of plastic clay was deposited, produced by glacial attrition of shales and limestones. The upper portion of the clay is more siliceous, and it is overlain by an extensive deposit of sand, indicating a change in the nature of the material washed into the estuary. During the period of submergence much of the siliceous matter washed into the estuary was deposited at the mouths of tributary streams to form deltas.

The clays of the Champlain valley are estuary deposits of the same age as the Hudson river clays. They underlie terraces bordering Lake Champlain, and now standing at an elevation of 393′ A. T. Extension erosion has removed much of the clays and sands, and it is only at sheltered points that the terraces are now prominent. The clays are worked for brick at Plattsburg and other localities.

Cretaceous clays occur on Staten Island, and have been worked extensively at Kreischerville and other points, the material being used in the manufacture of fire-brick, etc.

[1] "There is still some doubt as to the exact conditions under which the beds of clay and gravel which form the greater portion of Long Island were deposited, but it is probable that the clays represent shallow water marine deposits of Cretaceous and Tertiary age . . . . The age of the clays is still largely a matter of speculation, and will probably remain so in many cases unless paleontologic evidence is forthcoming. Those on Gardiner's Island are quite recent, as shown by the contained fossils, and the clay on Little Neck is Cretaceous. The proof of the age of the Glen Cove clay is not absolute . . . . The clays at Center Island, West Neck, Fresh Pond, and Fisher's Island are very similar in appearance and composition, and are very probably of the same age, possibly Tertiary, but we lack paleontologic or stratigraphic evidence. At West Neck, the clay underlies the yellow gravel and the latter is covered by the drift, so that is pre Pleistocene."

Shales occur in New York in the Hudson River, Medina, Clinton, Niagara, Salina, Hamilton, Portage and Chemung groups. Of these, the last three are the most

[1] In regard to the Long Island clays the author has been quoted verbatim, as the statements could not well be summarized.—E. C. E.

important in the present connection, though Medina shales are used in Ontario in the manufacture of pressed brick, while vitrified brick are made from Salina shales at Warners, Onondaga county, N. Y. Hamilton shales are utilized at Cairo, Greene county, in the manufacture of paving brick ; and at Jewettville, Erie county, for pressed brick manufacture. Sewer pipe, drain tile and terra cotta are made from Portage shales at Angola, Erie county. Chemung shales are utilized at Jamestown, Chautauqua county; Alfred, Allegany county; Hornellsville, and Corning, Steuben county; and Horseheads, Chemung county.

Feldspar and quartz are obtained from large pegmatite veins occurring near Bedford, Westchester county, and are shipped to the potteries at Trenton, N. J.

Report on Louisiana Clay Samples. Geological Survey of Louisiana, Report for 1899. Pp. 263–275.

Discussion of origin, composition and properties of clay, followed by reports on physical tests of six samples of clay. All of the clays tested could be used in the manufacture of pressed brick, while one could also be used for paving brick and two for earthenware.

Clay and its Manufacture into Brick and Tile. Mineral Industry, Vol. IX, pp. 93–135, 12 figures, 1901.

Detailed discussion of the manufacture of building and paving brick, roofing and floor tile, terra cotta and sewer pipe.

Report on the Clays of Maryland. Special Publication, Vol. IV, Pt. III, Maryland Geological Survey. 8vo, pp. 203–507; Pls. XIX–LXIX, including six geologic maps ; Figs. 5–34, 1902.

A general discussion of the origin, properties, uses and technology of clays is followed by detailed descriptions of the Maryland clays, and a résumé of the industries based on them.

According to Shattuck, the Pleistocene of Maryland is divisible into three formations ; the Talbot, Wicomico, and Sunderland. The newest of these, the Talbot, does not exceed forty-five feet in thickness ; and often carries lenses of greenish-black clay. The Wicomico, which is from forty-five to one hundred feet thick, seldom contains clay deposits of economic value. The Sunderland contains clay beds which are well shown in Calvert and St. Mary's counties. None of the Pleistocene clays are used for anything except common brick, though occasionally clays occur fit for tile or terra cotta.

The Neocene is represented by the Lafayette and Chesapeake formations. The Lafayette consists of gravels, sands and clays, very irregularly stratified, and changing character rapidly along the deposition planes. The Chesapeake consists chiefly of sands of marls with only local developments of clay.

Clark and Martin divide the Maryland Eocene as follows :

GROUP.	FORMATION.	MEMBER.
Pamunkey	Nanjemoy	Woodstock
		Potapaco.
	Aquia	Paspotansa
		Piscataway.

Of these four members only one, the Potapaco, contains clay deposits of importance. The Potapaco consists of argillaceous (and often gypseous) green sand, with a

lower clayey member which is shown south of South River. The clay is a fine grained material with occasional streaks of sand, and is in places twenty feet thick. It is fairly plastic, abundant, and exposed near tidewater; suitable for use in the manufacture of pressed brick and possibly of paving brick.

The Jurassic and Cretaceous of Maryland are divisible as follows:

Upper Cretaceous	Rancocas	
	Monmouth	
	Matawan	
Lower Cretaceous	Raritan[2]	Potomac group.
	Patapsco	
Jurassic (?)	Arundel	
	Patuxent.	

The Upper Cretaceous formations include no clay deposits of economic value; but the Potomac group is of great importance. The Raritan[1] consists usually of white sands and light colored clays, and reaches a thickness in central Maryland of one hundred[2] feet. Raritan clays are found in Cecil, Kent, Harford, Baltimore, Anne Arundel, Prince George's, Howard, and Montgomery counties. They are worked at several points for use in pressed brick manufacture; while potter's clay occurs in places. The Patapsco includes brightly colored mottled clays, with light sands and clays, and has a maximum thickness of about 200 feet. In Cecil county a bed of bluish stoneware clay often underlies the variegated clays. Refractory clays, as well as brick clays, occur, and the Patapsco clays have been exploited to a considerable extent. The Arundel contains lenses of bluish, siliceous, plastic clays, often carrying iron concretions. The clays are largely used in the manufacture of common and pressed brick, terra-cotta, roofing tile, and common pottery. The Patuxent consists largely of sands, with occasional beds of sandy clay, and is, in this regard, the least important member of the Potomac.

Shales from the different formations of the Carboniferous, Devonian and Silurian have been tested and found suitable for various uses. At present only two of these formations furnish material of economic importance, these being the Pottsville formation of the Carboniferous and the Jennings formation of the Devonian. Both flint clays and plastic clays occur in the Pottsville formation, the well-known Mt. Savage fire clay being an example of the former. The beds have been opened near Frostburg, at Mt. Savage and west of Ellerslie; and will probably become of even greater economic importance. Shales of the Jennings formation are extensively used in the manufacture of paving brick at Cumberland.

Kaolin occurs at many points in the area underlain by Algonkian rocks, notably in Cecil county. These residual clays, having been derived from feldspathic rocks low in iron-bearing minerals, are light colored and burn white. Only one company is actually at work mining and washing this material, but the industry will probably increase rapidly in importance. Owing to the presence of Patuxent and Columbia beds, the kaolin is rarely exposed at the surface, the necessary stripping varying from two to forty feet.

[1] On page 397 the Raritan is excluded from the Potomac, but is included in it on pages 399 *et seq.*—E. C. E.

[2] Elsewhere in the volume stated as 500 feet.—E. C. E.

Less-pure residual clays, derived from rocks of various kinds and ages, are found at many points in the state, and are used in places for brick manufacture.

SIEBENTHAL, C. E. *The Silver Creek Hydraulic Limestone of Southeastern Indiana.* Twenty-fifth Ann. Rept. Indiana Dept. Geology and Natural Resources Pp. 331–389, Pl. 14, colored geologic map, 1901.

Divided into three sections relating respectively to the stratigraphy, topography and economic geology of the Silver Creek limestones.

A historical résumé of opinions in regard to the stratigraphy of southeastern Indiana is followed by descriptions of local distribution and structure. The Devonian and sub-Carboniferous formations occurring in this area, with their New York and Mississippian (paleontologic) equivalents, are:

Sub-Carboniferous	Knobstone	Kinderhook.
	Rockford limestone	Choteau.
Devonian	New Albany black shale	Genesee.
	Sellersburg limestone	Hamilton.
	Silver Creek hydraulic limestone	Hamilton.
	Jeffersonville limestone	Corniferous.
	Pendleton sandstone	Schoharie.

The topography is briefly mentioned. Pleistocene terraces are described and mapped, and a possible preglacial channel of the Ohio River is pointed out.

The Silver Creek hydraulic limestone is massive, very fine grained and usually fossiliferous. In color it varies from light to dark or bluish-drab, weathering buff. In composition it varies between the following limits: Calcium carbonate 52 per cent. to 62 per cent.; magnesium carbonate 16 per cent. to 35 per cent.; silica 9.5 per cent. to 18.5 per cent.; ferric oxide 1.4 per cent. to 2.0 per cent.; alumina 2 to 5 per cent. The cement rock is obtained by quarrying or mining, according to the situation; blasted out by dynamite and sledged to proper size (6″–12″) for the kilns. The latter are continuous up-draft kilns, and require about seventy-two hours for calcination. The burned rock is sent through crushers, "re-grinders," and rock-emery mills. During 1900, thirteen plants, working 116 kilns, were in operation, the total product being 2,512,000 barrels.

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THE

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A QUANTITATIVE CHEMICO-MINERALOGICAL CLASSIFICATION AND NOMENCLATURE OF IGNEOUS ROCKS.

CONTENTS.

SUMMARY.

We present in this work an entirely new system for the classification and nomenclature of igneous rocks, which represents the results obtained after some years of consideration and discussion of the subject in all its bearings.

In uniting our efforts for this purpose we have been actuated by a sense of the seriousness of the responsibility assumed in such an undertaking, and by a conviction that the best results were to be obtained by the co-operation of several workers who agreed on fundamental principles and who were capable of harmonious collaboration.

Originally Professor George H. Williams was associated with us in this work. By his death we have been deprived of a counselor whose judgment we held in the highest esteem, and whose loss we cannot cease to lament.

Many attempts were made to modify in various ways the existing systems of classification in the endeavor to make them answer the demands of modern petrology, and each attempt was successively cast aside on practical trial. It came thus to be perceived by all of us that the main weakness of old systems lay in their fundamental principles and methods and that any new, logical and comprehensive system based on the vast amount of knowledge of igneous rocks acquired in these later

years must be built up from the very beginning on different lines from those heretofore employed. After many endeavors in various directions, we gradually evolved the system here presented. Along with its evolution has gone hand in hand the calculation of thousands of analyses by which it has been tested and its formation in large part controlled. It is a *chemico-mineralogical* system based on its own principles, and is in nowise an attempt to reduce any one of existing systems to a chemical basis or to formulate one of them in a chemical way. Its concepts of rocks are in a large measure new, and hence, except in a very small degree, it demands a new nomenclature.

In brief outline, what we propose is as follows: All igneous rocks are classified on a basis of their *chemical composition*; all rocks having like chemical composition are grouped together. The definition of the chemical composition of a rock and of a unit of classification is expressed in terms of *certain minerals* capable of crystallizing from a magma of a given chemical composition, and the expression is *quantitative*. For this purpose the rock-making minerals are divided into two groups, consisting on the one hand mainly of the more highly siliceous alkali- and calci-aluminous ones, and on the other of the ferromagnesian ones. The first group is called mnemonically the *salic* group, the second is the *femic* group. From this category the micas and aluminous augites and amphiboles are excluded for reasons given in full.

For the purpose of completely classifying a rock by this system its chemical composition must be actually known by chemical analysis, or approximately so by physical means or by microscopic, optical methods indicated by the authors. The thousands of rocks of various mineral compositions and textures whose places in this system are indicated by chemical analysis become types for comparison, analogous to type specimens of zoology and botany, by which similar rocks may be approximately classified.

Since it is known that many magmas may crystallize into quite different mineral combinations, according to the influence

of attendant conditions upon the union of the various chemical constituents of the magma, it is necessary to select a certain set of salic and femic minerals as uniform standards of comparison. These standard minerals are, for the most part, species commonly formed, but the aluminous pyroxenes, amphiboles, and micas are necessarily excluded. In practice, the molecular composition of a rock, obtained from its chemical analysis, is computed by a regular method into amounts of these standard minerals, and the place of the rock in the system is then easily determined.

The *standard mineral composition* of a rock is called its *norm*, and this may be quite different from its *actual mineral composition*, or *mode*. Methods for obtaining the latter and for indicating its relation to the former are set forth in detail in the Part III, on Calculations.

On the relative proportions of these two groups of standard minerals, the rocks are first divided into five *Classes*, accordingly as one or the other of these two groups alone constitutes the norm, or is *extremely* abundant; whether one or the other is *dominant;* or whether the two are in about *equal* proportions. The *Classes* thus formed are divided into *Orders* on the relative proportions of the minerals forming the predominant group in each case, and in the middle group on the relative proportions of the salic minerals. Thus in the preponderantly salic Classes the Orders are based on the relative amounts of quartz, feldspars, and feldspathoids.

The *Orders* are divided into *Rangs* on the chemical character of the bases in the minerals of the preponderant group in each case; thus, if these were feldspathic, as to whether they are alkalic, alkalicalcic, or calcic. The lowest division or *Grad* obtains only in the three intermediate Classes, and results from the consideration of the relative amounts of the minerals composing the subordinate group.

In addition to these divisions further ones are provided for where necessary by Subclasses, Suborders, Subrangs, and Subgrads.

Texture is considered of minor importance in classification, and is taken into account after the chemical and mineral composition.

Nomenclature.—The system demands an entirely new nomenclature, and it has been sought to introduce this according to a definite system, the lack of which is so painfully evident in the present nomenclature.

The nomenclature proposed consists of three parts: primarily of substantive names for the magmatic units, implying the chemical composition and the norm, or *standard* mineral composition; secondarily, two sets of adjective terms to be used to qualify the magmatic names; one set referring to the actual mineral composition, or mode, and the other to the texture of the rocks.

The magmatic name consists of a root, derived from a geographical name in all cases except for the names of Classes and Subclasses, and of a suffix. The suffixes are so chosen as to vary in a definite way with the division of the system to which the magmatic name belongs. Thus for Class, Order, Rang, and Grad, the letters *n*, *r*, *s*, and *t* in alphabetical order are used with the vowel *a*, giving in English *ane*, *are*, *ase*, *ate*. For Subclass, Suborder, etc., the vowel is changed to *o*, giving *one*, *ore*, *ose*, *ote*.

The roots forming the names for classes are *sal* and *fem*, mnemonic of the salic and femic minerals constituting their norms, and are combined with prefixes yielding the following: Persalane, Dosalane, Salfemane, Dofemane, and Perfemane.

The roots for the names of the divisions smaller than Class are derived from the names of geographical localities, and as far as possible from those at present in use for rock names, advantage being taken of their connotations as to magmatic character.

The authors propose a nomenclature for field use based on purely megascopic characters.

The work concludes with a discussion of methods of calculating mineral composition from chemical composition and the reverse, and presents tables to aid such calculations.

PART I. CLASSIFICATION.

INTRODUCTION.

The commonly acknowledged unsatisfactory character of rock classifications in present use, and the unsystematic nomenclature of petrography, have convinced us of the necessity for a complete reconstruction of both. Recognizing the magnitude of this task, yet desiring to see it accomplished as early as possible, we have united our efforts toward the production of a new system of classification and the creation of a nomenclature to express it. Many attempts at improvement of existing schemes of classification have been made in recent years, but they have failed to accomplish important results because they have not gone to the root of the matter.

The discussions of petrographers associated with the International Geological Congress have demonstrated the futility of attempting the regulation of petrographical nomenclature without first fixing the basis of rock classification, since the conceptions by different petrographers of the objects to be named are diverse. And the effort to establish a systematic classification of igneous rocks by international conference and agreement has in like manner proved ineffective because of evident inherent difficulties.

The recently published *Compte Rendu* of the Eighth Session of the International Geological Congress, held in Paris, furnishes an illustration of the diversity of views held by European petrographers, while presenting in definite form the convictions of a considerable number of the foremost workers in this science regarding the principles that should govern the choice of bases of a systematic classification. To a very considerable extent we find ourselves in accord with the opinions expressed in the report of the Russian Committee and in the discussions and report of the Paris Commission of October, 1899. And we are encouraged to hope that the system here presented by us will meet with a cordial reception by those petrographers who, sharing more or less completely our conceptions of the fundamental principles that

should control the formation of a systematic classification of igneous rocks, may approve of our method of applying them.

We wish to acknowledge our obligations to all those whose ideas and writings have influenced us consciously or unconsciously; influences which will be evident in many places in the succeeding pages. It is not always possible to credit a particular conception to a particular author. The science of petrography has developed so rapidly, and so many workers have been engaged upon kindred problems, that similar ideas have forced themselves upon investigators. Especially, in our own case, frequent interchanges of thought have so blended and modified our ideas that is difficult for any one of us to identify his own.

In particular we acknowledge our obligations to those masters of petrography from whom we caught inspiration for our petrographical careers. To Professor Ferdinand Zirkel and to Professor Heinrich Rosenbusch, our instructors, whose work and thought have opened the way to a host of students of rocks, we are indebted for much that has influenced us in shaping the system proposed, which is in fact a natural outgrowth of present petrographical conditions.

Defects of present systems.—From the review of rock classification in an earlier part of this volume by one of us, it appears that all past and existing classifications of rocks have fundamental weaknesses arising either from the use of theoretical concepts, or from an inconsequent or illogical application of the characters of igneous rocks as bases of their systematic arrangement. That a new nomenclature is required for a new system can scarcely be disputed. The present confusion in petrography is in no small degree due to redefinition of old terms, and to this confusion we have no desire to add. Without going into an extensive discussion of the vitally weak points of existing systems of petrography, upon which all of us have expressed individual opinions, some of the most unsatisfactory features may be briefly stated as follows:

1. There are few definite, clearly enunciated and generally applicable guiding principles, the consequence being that the

present systems are to a large extent arbitrary aud subjective, and are capable of being applied differently by different individuals, as is evident from the numerous cases where different names have been given to the same rock, or the same name to obviously different rocks.

2. There is a lack of uniformity in the method of application of existing systems not only among petrographers of different countries, but among those of the same country.

3. The present systems are to a certain extent founded on theory or hypothesis, while classification in order to be stable must eschew all such bases, and be founded only on ascertained facts.

4. Present systems are to a large extent qualitative rather than quantitative, the result being that some given character of rocks is arbitrarily used as a criterion beyond its natural range of application, as, for example, the use of the mere presence of feldspar to distinguish a group of rocks, whether it be the dominant constituent or only a very subordinate one.

5. The construction of modern systems is faulty in that the groups of rocks, or of rock families, now recognized are quite inadequate to express known relationships, and the varying groupings used by different authors are not based upon definite principles, nor are the principles applied uniformly. As a result of this condition, existing systems are highly uneven and it is often necessary to use either too specific or too general terms in naming a given rock.

6. The nomenclature of petrography is quite inadequate to express the relations between the various groups. The single termination makes it impossible to indicate in the name, *per se*, whether it applies to a large or to a small classificatory division, or whether to rocks or minerals, and gives rise to great monotony.

7. As a consequence of these conditions, there is no guide as to when the use of a new name is necessary or justified, each investigator being his own judge in such matters. In some rock groups which have been recently studied, there is an abundance of new names, while in other more common and longer known

groups, a few names are made to do duty for many obviously distinct rocks.

Upon the grounds stated, a new system of petrography seems to us necessary. This conclusion has been reached by us only after many efforts to revise or remodel existing schemes. Our first conferences upon this undertaking were participated in by George Huntington Williams, and our first exchange of suggestions bears the date of May 1, 1893. These efforts on our part, extending over ten years, have brought us from somewhat diverse views to full accord in the system here presented.

BASIS OF CLASSIFICATION.

The progress in the knowledge of the composition, texture, and occurrence of igneous rocks, as well as in the conceptions of the probable causes of variation among different bodies and within one body of rock, has been such as to justify us in considering the problem of the classification of igneous rocks in the light of certain established facts of a general nature. The recognition of these leads to the establishment of general principles upon which a new system of classification may be based.

The facts to be considered may be stated categorically as follows:

The once igneous or molten condition of the magmas from which rocks of this kind have solidified.

The characters of such magmas as solutions.

The physical and chemical properties of such solutions.

The ability of complex solutions to differentiate by osmotic diffusion, liquation, fractional crystallization, or by other processes, under varying conditions of temperature and pressure.

The variations in chemical composition resulting from such differentiation.

The existence of marked chemical variations within igneous masses of small volume in some instances, and of slight variations within bodies of large volume in others.

The absence of fixed proportions of constituents in rocks with two or more mineral components.

The gradations in the chemical and mineral composition of rocks, within limits.

The limited number of the important rock-making minerals.

The existence of rocks having but one mineral component.

The variable crystallization of a chemically homogeneous magma, or of several chemically similar magmas, whereby different combinations of minerals may be produced from chemically similar magmas. In other words, the fact that rocks having diverse mineral compositions may be chemically alike.

The fact that diverse textures develop from the same magma and from chemically similar magmas, and conversely that similar textures develop from chemically different magmas.

The incomplete crystallization of magmas or their solidification into glass in many instances.

The identity of rocks of different geological ages.

The identity of many rocks with different modes of geological occurrence.

The existence of petrographical provinces in which the igneous rocks genetically related are distinguishable from those of other regions, when considered in connection with the occurrence elsewhere of similar petrographical provinces and with the gradual transitions between provinces, should be treated as a larger phase of differentiation. Moreover it has been shown by Brögger[1] that similar rocks may be differentiated from different parent magmas in several petrographical provinces, and may occur in two or more unlike series. That is, rocks belonging to distinct provinces may resemble one another so closely in their dominant characters that they would naturally be defined by the same terms. Hence, we conclude that all igneous rocks should be correlated and classified in one comprehensive system based upon principles common to igneous rocks in general.

The principles which we consider applicable to the classification of igneous rocks, as criteria by which to judge of the facts

[1] *Quart. Jour. Geol. Soc.*, Vol. L (1894); p. 36, and *Die Eruptivgesteine des Kristianiagebietes*, Vol. III, p. 57, Christiania, 1898.

to be employed and their method of application, are as follows:

The classification should be free from hypothesis, and be based only on facts or relations determinable in the rock itself.

The classification should be quantitative as far as possible, and each constituent, chemical or mineral, should be given weight in proportion to the amount present in each case, irrespective of its rarity or unusual occurrence.

The chemical composition of the rock is its most fundamental character, being a quality inherent in the magma before its solidification, and is therefore of greatest importance for its correlation with other rocks.

All rocks of like chemical composition should be classed together, and degrees of similarity should be expressed by the relative positions or values of the systematic divisions of the classification.

The mineral and textural characters, being dependent largely on external conditions attending rock solidification, are to be regarded as of subsidiary importance in classification, but should receive due recognition in the system.

Since it is the chemical composition of the magma that is the fundamental character of igneous rocks by which they are to be classified, only fresh, undecomposed, or unaltered rocks are to be employed in establishing such a classification.

A BRIEF DISCUSSION OF VARIOUS PRINCIPLES that have entered into systems of rock classification is introduced at this place in order to make clear our reasons for selecting those employed in creating the system proposed by us.

Rocks have always been recognized as extremely difficult of systematic classification, because of their infinite variation or gradation from one kind to another in many ways. Reviewing the many factors which may be employed in their classification, they are found to fall into two groups, namely, geological relations, and inherent characters; and the task of the systematic petrographer is to select the characters and apply the criteria

which will produce the most natural and stable as well as comprehensive and elastic arrangement.

Of geological relations, the mode of origin is now universally recognized as the first principle to apply to the sub-kingdom of rocks, to secure the grand divisions of which the igneous rocks are one. The further application of geological mode of origin in subdivision of igneous rocks involves the use of theoretical considerations and produces instability of system.

The relations of geological occurrence have been used in the arrangement of igneous rocks, but unsuccessfully. Geological age cannot now be used without violating the known fact that rocks of many ages are identical in their material qualities.

Some systems of classification now in use are based on supposed relationships between the material characters of igneous rocks and their modes of occurrence as geological bodies, which are only partially in accord with facts, and which therefore introduce serious weakness into the foundation of the systems. There are no particular kinds of rocks that invariably characterize geological bodies of special shapes, such as stocks, laccoliths, dikes, etc. Nor is there any specific texture that indicates the depth beneath the surface of the earth at which a rock has crystallized. While there is unquestionably a relation between the texture and mineral composition developed in a given magma and its physical environment during eruption and intrusion and at the time of its solidification, this relationship is so intricate, and the possibilities of environment so manifold, that it cannot be made a basis for classification.

The effort to classify rocks on a basis of their genetic relationships by grouping them in such a manner as to express the fact that all the rocks of a particular center of eruptive action are the differentiates of some common parent magma introduces the utmost complexity, because each group presents a particular set of relations, and it becomes necessary to recognize almost as many groups as there are known centers of eruption. But as already stated, the members of several groups may resemble one another so closely as to be capable of the same definition and

deserving of the same name. The consistent application of such a system of grouping would therefore separate rocks which are alike so far as intrinsic qualities are concerned. And this, according to our conception of classification, is not classification. Many of these facts are essential to the complete petrological understanding and description of rocks, but are not applicable to the construction of a petrological system.

The inherent characters of igneous rocks have always been prominent in the formation of petrographic systems, and are plainly the features it is most natural to select. This was specially pointed out by the fathers of systematic petrography, von Leonard and Brongniart, and has been emphasized in recent discussions. Of these characters chemical and mineral composition, structure or texture, are the most important, the others being comparatively trivial or accidental. Structure or texture is now known to depend so largely on variable conditions attending the consolidation of magmas that it can no longer be given the prominent rôle hitherto assigned to it. Chemical and mineral composition then remain as those characters of igneous rocks most available for their classification. Of these, it is to be noted, that while the two are most intimately related, the former is more fundamental, since it pertains to a magma which may consolidate as a glass or become a holocrystalline rock, and in the latter case the mineral constitution varies with attendant conditions.

CHEMICO-MINERALOGICAL CLASSIFICATION.

While the chemical composition of igneous rocks is their most fundamental characteristic, it is known that there is an absence of stoichiometric proportions among the chemical elements or components. It is further clear that there is an intricate interrelationship and serial variation among these components and an absence of chemical division lines, or of groups or clusters of similar combinations of elements. These facts show that any subdivision on a purely chemical basis must be arbitrary, unpractical and unsatisfactory.

All holocrystalline, and many of the partially crystalline

rocks derive their most obvious characters from the mineral particles composing them. The varying proportions of unlike minerals in rocks are most striking, and other notable features are due to the physical properties of the minerals, their color, cleavage, hardness, etc., or to the relative or absolute size or shape of the particles. It is by reference to these characters that rocks may be most readily described and identified, and it is then desirable that the systematic classification should be constructed as far as may be by the use of mineralogical data in one form or another.

There are, however, reasons why mineral constitution by itself cannot be used in the principal divisions of a comprehensive and logical classification of all igneous rocks. The existence of vitreous rocks forms one of these reasons, because such rocks cannot be classified at all by purely mineralogical criteria. The fact that a given magma may crystallize into different mineral combinations is another reason. Moreover, if mineral composition were a simple function of chemical composition, and if all rocks were holocrystalline, the number of chemically different minerals of importance would make the task of classifying rocks by means of mineral composition alone practically impossible. It, therefore, appears that neither chemical composition nor mineral constitution can be independently applied to the construction of a logical and practical classification of igneous rocks.

The primary minerals in a holocrystalline igneous rock, when considered *chemically* and *quantitatively*, are a full expression of the chemical composition of the magma, and their exact determination furnishes the chemical composition of the rock. To a large extent the mineral composition may be employed as a means of determining the chemical composition, and since the minerals are readily determinable optically in many cases and are a convenient means of identifying rocks, it is advisable *to treat the chemical composition of rocks in terms of minerals*, and to make the basis of primary subdivisions *chemico-mineralogical*.

While this conclusion is, in its general terms, quite com-

monly asserted as the purpose of existing mineralogical systems of rock classification, it requires but casual consideration to see that a *qualitative* mineralogical system cannot express chemical composition, and a thoroughly *quantitative* scheme has never been formulated.

Before stating the method of classification to be proposed, it is important to point out some of the chemical and mineralogical relationships obtaining in igneous rocks. And first it is to be noted that while the chemical composition of a magma controls in general the kinds of minerals that may crystallize from it, so that quartz forms in the more siliceous rocks, and olivine in those rich in magnesium and iron, still it does not fix absolutely the kinds or the proportions of all of the rock-making minerals. This is due to the fact that a number of these minerals consist of similar elements in diverse proportions, so that two or more different combinations of elements may be developed in chemically similar magmas. Or, as is well known, some of the minerals having a complex composition may be dissociated into less complex ones. A familiar example is the experimental melting of hornblende and the obtaining in its stead pyroxene and magnetite. Another illustration of the same kind of relationship is the chemical identity of some hornblende-andesites and some pyroxene-andesites.

A striking illustration is furnished by the hornblendite and camptonite of Gran, Norway, described by Brögger.[1] The two rocks having almost identical chemical compositions are composed in the first case of somewhat alkalic, aluminous hornblende, and in the second of less aluminous hornblende and feldspar.

The development of biotite in some rocks and its absence from others having like chemical composition is well known; as shown by its presence in some gabbros and its absence from some chemically equivalent basalts; its presence in certain diorites and its absence from equivalent andesites;[2] its develop-

[1] *Op. cit.*, pp. 60, 93.

[2] IDDINGS, J. P., "The Eruptive Rocks of Electric Peak and Sepulchre Mountain, Yellowstone National Park," *Twelfth Ann. Rept. U. S. Geol. Surv.* (Washington, 1892), p. 653.

ment in minettes and absence from certain basanites. And with this difference in biotite there is a variation in olivine, hypersthene, magnetite and other minerals within the rocks mentioned.

Other notable illustrations of different mineral development in chemically similar rocks are the madupite of Wyoming[1] and venanzite of Italy,[2] in the latter rock melilite and olivine appearing instead of pyroxene and phlogopite in the madupite; also the nephelite-syenite of Beemerville, N. J.,[3] and the leucite-phonolite of Bracciano.[4] Indeed, instances of the same kind are well known to all, and are constantly increasing in number. It is therefore indisputable that magmas of identical chemical character may and do solidify as very different mineral aggregates, it being also a possibility that they form on solidification no minerals at all, or that they crystallize only in part.

STANDARD MINERAL COMPOSITION.—Whether vitreous or crystalline, all igneous rocks may be correlated by considering what mineral combinations may be developed from their magmas if completely crystallized. But since several mineral combinations are possible for most magmas, it is advisable to select one of these combinations as the standard of comparison. And for uniformity and simplicity it is necessary to select the same one for all rocks having like chemical composition. This may be termed the *standard mineral composition*, which may or may not correspond to the *actual mineral composition.*

Before presenting the reasons for selecting certain minerals as those best adapted for a chemico-mineralogical classification of igneous rocks, let us consider the important rock-making minerals from the general standpoint of their chemical composition. They may be arranged in several groups chiefly

[1] CROSS, W., "Igneous Rocks of the Leucite Hills, etc." *Am. Jour. Sci.*, Vol. IV (1897), pp. 115–141.

[2] SABATINI, V. I Vulcani di S. Venanzo. Rivista di Min. e Crist., Vol. XXII Padova, 1899, pp. 1–12. *Cf.* ROSENBUSCH. *Sb. Berl. Ak.* (1899) p. 113.

[3] *Bull. 150, U. S. Geol. Surv.* (Washington, 1898), p. 209.

[4] WASHINGTON, H. S., "Italian Petrographical Sketches," JOUR. GEOL., Vol. V (1897), pp. 43, 49.

distinguished by chemical characters, but also by associations in the rocks. They are:

a) *Silica and alumina uncombined,* quartz (tridymite) and corundum, together with zircon, which, though commonly present in very small amount, is oftenest found in rocks rich in silica or alumina.

b) *Aluminous non-ferromagnesian minerals;* orthoclase, albite, anorthite and mixtures of these, leucite, analcite, nephelite, sodalite, hauynite, noselite, cancrinite, and muscovite.

c) *Aluminous ferromagnesian and calcic silicates* (intermediate between *b*) and *d*)): aluminous pyroxenes and amphiboles, biotite, garnet, tourmaline, melilite, some spinels, etc.

d) *Non-aluminous ferromagnesian and calcic silicates:* hypersthene (including enstatite), diopside (including hedenbergite), acmite, olivine (including fayalite and forsterite), and akermanite.

e) *Non-siliceous and non-aluminous minerals with titanosilicates;* magnetite, hematite, ilmenite, apatite, titanite, perofskite, and fluorite, together with the native metals, and certain other metallic oxides and sulphides.

If igneous rocks are considered from the standpoint of their mineral composition, they are found to consist of graduating series of quantitatively different mixtures of several groups of minerals, and since they are all necessary to an exact expression of the chemical composition of the rock, each mineral or group of minerals should receive proper recognition according to its quantitative value. Owing to the number of minerals in most rocks, this is a very intricate problem and we have made repeated attempts to solve it by recognizing several independent mineral factors at one time, involving the problem of handling three or more co-ordinate quantities. This was found impracticable as a basis of classification, and it was seen that the most feasible procedure is to recognize such factors successively according to certain degress of qualities or magnitudes possessed by them in comparison with one another. This has been done by grouping them on a basis of chemical identity or resemblance, and of

established affinities or associations, and by successively subdividing these groups by subordinate chemical differences or quantitative values. For this purpose it is necessary to assemble all rock-making minerals into two chemically distinguished groups.

These have been made by uniting quartz, corundum and zircon with the aluminous non-ferromagnesian minerals — feldspars, feldspathoids and muscovite — in one group, and by placing the non-aluminous ferromagnesian and calcic minerals — hypersthene, diopside, acmite, olivine, and akermanite — with the non-siliceous and non-aluminous minerals, and titanosilicates, — magnetite, hematite, ilmenite, apatite, etc. — in the other group.

This leaves the aluminous ferromagnesian minerals to be treated in another manner. The reasons for this separation of the minerals, biotite, amphibole and augite, are discussed at length in a later part of this article, but it may be said here that their variable composition and occurrence, together with the fact that they may be considered as mixtures of aluminous and non-aluminous molecules, make it advisable to defer their introduction into the system of classification until the actual mode of crystallization of the rocks is taken into account. Since it is possible that a magma of any given chemical composition may crystallize without the development of these minerals, and since the chemico-mineralogical expression of igneous magmas is greatly simplified by not considering these minerals until the particular crystallization of the magma is to be expressed, we are justified in omitting them from the two groups of minerals which are to be employed in determining the standard mineral composition of an igneous rock. These two groups of *standard minerals* are:

GROUP I: SALIC MINERALS.

Quartz, SiO_2		Q
Zircon, $ZrO_2 . SiO_2$		Z
Corundum, Al_2O_3		C
Orthoclase, $K_2O . Al_2O_3 . 6SiO_2$	or	F
Albite, $Na_2O . Al_2O_3 . 6SiO_2$	ab	F
Anorthite, $CaO . Al_2O_3 . 2SiO_2$	an	F

Leucite, $K_2O.Al_2O_3.4SiO_2$	lc		
Nephelite, $Na_2O.Al_2O_3.2SiO_2$	ne		
Kaliophilite, $K_2O.Al_3O_2.2SiO_2$	kp	L	
Sodalite, $3(Na_2O.Al_2O_3.2SiO_2).2NaCl$	so		
Noselite, $2(Na_2O.Al_2O_3.2SiO_2).Na_2SO_4$	no		

GROUP II: FEMIC MINERALS.

Acmite, $Na_2O.Fe_2O_3.4SiO_2$	ac		
Sodium metasilicate, $Na_2O.SiO_2$	ns		
Potassium metasilicate; $K_2O.SiO_2$	ks	P	
Diopside, $CaO.(Mg, Fe)O.2SiO_2$	di		
Wollastonite, $CaO.SiO_2$	wo		
Hypersthene, $(Mg, Fe)O.SiO_2$	hy		
Olivine, $2(Mg, Fe)O.SiO_2$	ol	O	
Akermanite, $4CaO.3SiO_2$	am		
Magnetite, $FeO.Fe_2O_3$	mt		
Chromite, $FeO.Cr_2O_3$	cm	H	
Hematite, Fe_2O_3	hm		M
Ilmenite, $FeO.TiO_2$	il		
Titanite, $CaO.TiO_2.SiO_2$	tn	T	
Perofskite, $CaO.TiO_2$	pf		
Rutile, TiO_2	ru		
Apatite, $3(3CaO.P_2O_5).CaF_2$	ap		
Fluorite, CaF_2	fr		
Calcite, $CaO.CO_2$	cc	A	
Pyrite, FeS_2	pr		
Native metals and other metallic oxides and sulphides.			

Sal, Fem, and Alfer.—For convenience in subsequent discussion, we will anticipate the question of nomenclature, and introduce here three terms which will be frequently used. To express concisely the two groups of standard minerals and their chemical characters in part, the words *sal* and *fem* have been adopted. The former is employed to designate Group I, mnemonically recalling the *s*iliceous and *al*uminous character of its minerals. *Fem* indicates Group II, since its minerals are dominantly *fe*rro*m*agnesian. As adjectives to express these ideas the words *salic* and *femic* will be used. In certain formulæ employed later the words *sal* and *fem* will be used in the sense just explained, as indicating any one or all of the minerals of the respective groups. Subsequently other mnemonic syllables will be similarly treated.

The intermediate group *c*) of aluminous ferromagnesian and calcic silicates will be designated *alfer* or *alferric* group, this name recalling the fact that these minerals are characterized by the presence of *al*umina and *fer*ric oxide.

Group I.—The minerals of groups *a*) and *b*) have been united to form the salic group (I) because of the well-recognized relations between the development of quartz, feldspar and feldspathoids in rocks and the available silica in the magmas; these minerals forming frequent series of rocks with a regular range of silica. It is also done because of the association of notable amounts of zircon and corundum with these minerals in the more quartzose and feldspathic rocks. And further it is in accord with the stronger affinities of the bases, potassium and sodium, for silica and alumina, which will be discussed later.

The kaliophilite molecule is recognized, since its presence is necessary in a few magmas so low in SiO_2 as not to allow the formation of both leucite and akermanite. Muscovite is omitted from the list in order to simplify the process of calculation. It may be considered as made up of orthoclase with corundum and water. Analcite is also omitted for a similar reason. It may be considered to be composed of albite, nephelite and water. Hauynite is omitted because it may be regarded as calcic noselite, and because it introduces needless complications into the calculation. The standard SO_3-bearing feldspathoid is therefore considered to be a purely sodic noselite. Cancrinite is likewise omitted as being in most cases of secondary origin, as well as for purposes of simplification.

Group II.—The minerals of groups *d*) and *e*) have been united to form the femic group (II) because of their freedom from alumina and their association in notable amounts in rocks low in silica and alumina. They are in this sense antithetical to the salic minerals.

Wollastonite ($CaSiO_3$) is added to the list of femic minerals in order to simplify the calculation of standard minerals in rocks rich in calcium, which may actually enter aluminous molecules, such as garnet.

The simple metasilicate molecule $Na_2O \cdot SiO_2$, analogous to that of wollastonite, is assumed to be present in rocks in which there is an excess of alkalies over Al_2O_3 and Fe_2O_3. It appears in the arfvedsonite molecule, which develops in such rocks. But this mineral, being alferric, is not included among the standard minerals for reasons already given.

In like manner the simplified *akermanite* molecule, $4CaO.3SiO_2$, is included among the standard minerals in place of melilite, because of the alferric character of the actual melilite, our uncertain knowledge of its real composition, and its complexity. The Na_2O and Al_2O_3 with $2SiO_2$ of melilite are calculated as entering into a nephelite molecule, the Fe_2O_3 is referred to magnetite or hematite, leaving the CaO, partly replaced by MgO, and the remaining SiO_2 in approximately the akermanite ratio of 4 : 3. The introduction of this molecule into the calculation is necessary in rocks so low in SiO_2 that a subsilicate must develop.

The molecule $(Mg, Fe)O.Fe_2O_3.SiO_2$, which is characteristic of augite, has been omitted for the reason that the ferric oxide is largely replaced by alumina, and because its introduction complicates the problem of calculation.

Method of calculation.—In order to determine the kinds and amounts of standard minerals that may express the composition of a given rock, to establish its place in the system, we may proceed by a consideration of its chemical composition as given by chemical analysis, or by a consideration of its actual mineral composition as determined by optical investigation, or we may compare it with known rocks whose compositions have been previously determined.

And since it is advisable to select the same mineral combination for the basis of comparison of chemically similar rocks, as already stated, and since there are gradual transitions among igneous rocks, it is necessary to follow the same method of procedure in calculating the kinds and amounts of the standard minerals for all rocks. The method adopted by us is explained in detail in a later part of this paper. It is based upon certain

well-known chemico-mineralogical relations affecting the salic and femic minerals, both as regards the proportions of their chemical constituents, the relative affinities of the bases for silica, and the frequent associations of certain of the rock-making minerals.

The method has been developed by considering, first, the chemical composition of igneous rocks, and by devising a plan for the calculation of standard minerals from it. Then, the *actual* mineral composition of holocrystalline rocks has been taken into account, and a plan devised, after reckoning the proportions of these minerals, for estimating their approximate chemical composition and from these data calculating the *standard* mineral composition of the rock.

It is evident that rocks that are not holocrystalline, or those in which the proportions of the actual minerals cannot be determined, must be classified in the first instance by means of chemical analysis. Subsequently similar rocks may be classified with greater or less precision by comparison with rocks having similar textures and the same actual mineral compositions, which have been analyzed chemically.

In comparing the relative quantities of different minerals in rocks, either their mass or their volume may be made the basis of comparison. In calculating the mineral composition from the chemical composition of the rock, the mass is the natural unit of comparison. The same is true if mechanical separation of the mineral constituents is undertaken. When a comparison is made by the eye, megascopically or microscopically, the basis of comparison is volume. This may be transformed into mass by multiplying the volume by the specific gravity of the mineral. The optical methods of estimation being less exact than those first mentioned, the basis of comparison should be mass.

CONSTRUCTION OF THE SYSTEM.

It is proposed to arrange igneous rocks by a system which shall express their quantitative chemical and mineral constitutions. With the known range and degree of variation in these

characters it is plain that any system of classification must be arbitrary.

As has been pointed out, the efforts to express the quantitative variation in rocks by means of several variables have shown that such a method is undesirably complicated. And we have sought to find a way for making groups of different taxonomic value by subdivision in a dichotomous manner based on the comparison of successive pairs of factors, since the simplest mode of construction is best.

The mineral constituents of igneous rocks may exist in all proportions from 0 to 100 per cent. whether considered as part of the whole rock, or as part of the group of standard minerals to which they may belong. For example one rock may consist entirely of feldspar, while another has none. And there are intermediate rocks containing all possible percentages of feldspar between these extremes. There are equally wide ranges for some of the chemical constituents, considered either with reference to rocks or to mineral groups. Thus the feldspars of one rock may be wholly alkalic, those of another wholly calcic, and between these extremes there are all possible gradations. Among alkalic feldspars are those purely potassic, others wholly sodic, besides all possible intermediate mixtures of these.

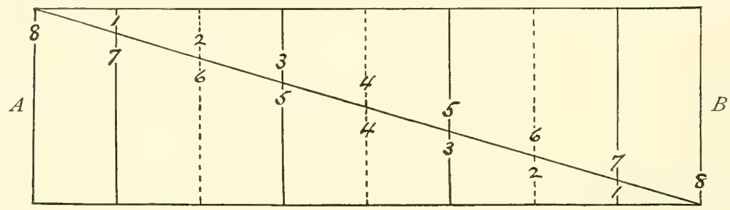
On account of the absence of natural division lines in such series of two variable factors, it is necessary to establish arbitrary divisions. We have accomplished this by considering certain simple proportions as *center-points*, about which variations may be allowed within limits, which limits become the boundaries between petrographical units.

The simplest proportions are: first, those two in which one factor constitutes the whole, and the other factor is absent; second, that in which both factors are present in equal amounts.

Other center-points should be selected with equal respect to these, and may be placed either midway between the three just mentioned, or at shorter intervals. It has appeared to us best to select those midway between the first three, namely, at points representing the proportions three to one, and one to three, making in all five divisions.

It will be noted that the rocks, or mineral or chemical groups, corresponding to the center-points of these divisions seem to have a special value as classificatory types, but we wish to point out that this is not actually the case. Such rocks or such groups, are not more important, considered quantitatively, than those occurring in any other part of the system, even on the boundary between neighboring divisions.

This fivefold method of subdivision may be expressed graphically as follows:



These divisions or units may be described as:

I. One in which the center-point is where the first group is present alone, 8:0.
II. One in which the center-point is where the first group is three times the second, 6:2.
III. One in which the center-point is where both groups are present in equal amounts, 4:4.
IV. One in which the center-point is where the second group is three times the first, 2:6.
V. One in which the center-point is where the second group alone is present, 0:8.

The dividing lines between these center-points will occur at the following ratios: 7:1, 5:3, 3:5, and 1:7. The ranges of the five divisions are given by the expressions:

$$\text{(I)}\ \frac{A}{B} > \frac{7}{1}, \quad \text{(II)}\ \frac{A}{B} < \frac{7}{1} > \frac{5}{3}, \quad \text{(III)}\ \frac{A}{B} < \frac{5}{3} > \frac{3}{5},$$

$$\text{(IV)}\ \frac{A}{B} < \frac{3}{5} > \frac{1}{7}, \quad \text{(V)}\ \frac{A}{B} < \frac{1}{7}.$$

The divisions may be defined in general terms as:

I. In which *A* is alone present or is *extremely* abundant.
II. In which *A dominates* over B.
III. In which both *A* and B are present in *equal* or *nearly equal* amounts.
IV. In which B *dominates* over *A*.
V. In which B is alone present or is *extremely* abundant.

The factor which is extreme or dominant over the other, will be spoken of as *preponderant*, the other being *subordinate*.

To indicate whether one of a pair of factors is present in greater or less amount than one-eighth of the combined pair of factors, that is, $\frac{A}{B} \gtreqless \frac{1}{7}$, we have adopted the terms *notable* and *negligible*. The former means that it is present in greater amount, and the latter that it is present in less amount, than that proportion.

It is to be noted that the smallest amount of any factor which we recognize as *notable* in a particular division of the system is one-eighth of the combined pair of factors, not necessarily one-eighth of the whole rock, since the pair of factors may be a fraction of the entire rock.

This fivefold method of subdivision will be further applied to that factor of a pair which is *extreme* or *dominant* over the other, or, in the case where both are present in equal amounts, it will be applied first to that one which is deemed to be of the greater importance, and subsequently, when necessary, to the less important factor.

In the case of one factor which is subordinate to another, but not negligible, $\left(<\frac{3}{5}>\frac{1}{7}\right)$, such a manifold subdivision is not advisable, since one-fourth of the factor in question would be less than one-eighth of the pair, and hence negligible. In this case we have adopted a threefold division, by retaining the central division of equal proportions $\left(<\frac{5}{3}>\frac{3}{5}\right)$, and uniting the dominant and extreme divisions. In these divisions there is one where two factors are equal or nearly equal $\left(<\frac{5}{3}>\frac{3}{5}\right)$, and two where one factor dominates or is extreme $\left(>\frac{5}{3}\right)$. Strictly, the

subdivision here should be into thirds, but, in view of the confusion liable to arise from the change in proportions the method adopted seems the most advisable one.

No subdivision need be made of a factor which is present in negligible amount, the other factor being extreme, since the whole subordinate factor falls within the allowable limit of variation.

It may be noted in this place that certain prefixes are used in connection with mineralogical and chemical terms to indicate that a factor is *extremely* abundant, or is *dominant.* In the first case the prefix is *per.* In the second case it is *do* or *dom.* When comparison is made on a threefold basis, and one factor *predominates* over another $\left(> \frac{5}{3}\right)$, the prefix is *pre.*

Since this classification is largely a chemical one, and since in all the calculations of minerals the molecular amounts of each constituent only are used, it must be borne in mind that all chemical comparison is made on the basis of the relative number of molecules, that is, it is purely molecular. For this purpose all percentages in analyses must be reduced to molecular ratios, by dividing each percentage by the proper molecular weight.

OUTLINE OF THE SYSTEM.

The subdivisions of igneous rocks proposed by us, based upon the principles discussed in the preceding pages are as follows:

Class, Subclass.
Order, Suborder.
Rang, Subrang.
Grad, Subgrad.

The word *Rang*, which is an obsolete form, equivalent to *Rank*, has been chosen instead of *Rank* to avoid confusion, since it is desirable that the technical term should differ from one which is in common use for other purposes. The same is true of *Grad* which is an old form of *Grade*.

The four terms — *Class*, *Order*, *Rank* and *Grade* — were at first selected because they are of the same category, the first two

being commonly used in classification. But Rank and Grade are so frequently employed in a general sense that it is advisable to substitute archaic forms in their stead.

These divisions, which are successively smaller, are based on characters of the magma of less and less importance. In other words, the highest divisions express the broadest and quantitatively most important magmatic characters, those next to them less important ones, and so on. It has been our aim to select the sequence of characters in accordance with this plan, and also to have homologous divisions throughout the system based on the same kinds of characters.

The broadest distinguishing chemical characteristics are expressed by the aluminous non-ferromagnesian minerals and their associates, quartz and zircon, the *salic* minerals, on the one hand; and by the ferromagnesian non-aluminous minerals and their associates, titanite, apatite, etc., the *femic* minerals, on the other.

Consideration of the salic and femic mineral groups shows, however, that the former is more simple in composition than the latter, so that certain modifications, not of the principles, but of their application, will be necessary in places.

Thus the salic minerals are composed chiefly of SiO_2 as representing the acid radical, with small amounts of Cl and SO_3 in the sodalite group, and of K_2O, Na_2O and CaO as representing the bases, these last being always accompanied by an equal amount of Al_2O_3, except in the sodalite group, where this is slightly less than the soda. The alumina, in most cases, reckoned among the bases, may play the rôle of acid to some extent in certain cases. On the other hand in the femic minerals, leaving apatite, fluorite, sulphides, etc., out of account, SiO_2, Fe_2O_3 and TiO_2 represent the acid radicals (the last two possibly uncombined with a base as hematite and rutile), and K_2O, Na_2O, CaO, MgO and FeO represent the bases.

Consequently, to keep to our system of two factors, already described, a more numerous subdivision of the divisions in which the femic minerals preponderate is necessary. But, as will be

seen, this can readily be done without transgressing the general principles on which the system is based or affecting the homologous characters of the various divisions in different parts of the scheme.

The principles on which the divisions enumerated above are made may be stated as follows:

Class.—This, the broadest division, expresses the most general chemico-mineralogical character of the magma, and is therefore based on the relative proportions of the salic and femic mineral groups as calculated in the standard mineral composition of each magma. In Classes all the salic minerals calculated for a magma are contrasted with all the femic minerals.

Subclass.—This division is based on certain broad chemical distinctions in the salic and femic groups, which make it possible to divide each of them into two parts. These will be explained in detail when these divisions are described at length later.

Classes and Subclasses exhibit the broadest and most general characters of the magma, and are based only on the salic and femic mineral groups, and the parts into which these may be most broadly divided on certain chemical lines. More special chemical characters of the salic and femic minerals in each class are next to be distinguished, and since both cannot be indicated at once, according to our principle of dealing with only two factors at a time, we consider first one group of characters and then the other. In accordance with the principle of giving importance to constituents on the basis of their relative proportions, the characters of the preponderant group, salic or femic, will be considered first until they are fully described, and then those of the subordinate group, femic or salic, will be taken up. The divisions from Order to Subrang are based on the chemical characters of the preponderant standard mineral group, while the divisions from Grad to Subgrad will be based on the chemical characters of the subordinate mineral group.

Order.—The salic minerals being in the great majority of cases silicates and quartz, and the silica being the most abundant

component of these silicates, it is quantitatively the most important chemical character of the salic minerals. Moreover the femic minerals in most rocks are silicates, and in them also silica is quantitatively the largest factor. Less abundant femic minerals are ferrates, titanates, and silicotitanates, besides still less frequent minerals of other kinds.

For these reasons the chemical characters of the salic and femic minerals of first importance quantitatively are the acid components, SiO_2, TiO_2, Fe_2O_3, which might be expressed uncombined with bases, or by mineral molecules. In order to express as far as possible the mineral composition together with the chemical it is advisable to express the relative amounts of these acids by means of mineral subgroups.

Orders in Classes with preponderant salic minerals are consequently based on the proportions of quartz to the feldspars, and of feldspars to feldspathoids, since these proportions correspond to differences of SiO_2 in the salic minerals. In Classes with preponderant femic minerals Orders are based on the proportions between silicate and non-silicate minerals in the first instance, and the recognition of the other acid components occurs in subdivisions of Orders.

Suborder.—In those Orders in which there are preponderant amounts of acid components other than silica, the most frequent of these being Fe_2O_3 and TiO_2, we may distinguish the relative proportions of these in Suborders. They occur in those parts of the system where minerals of the M subgroup preponderate.

Rang.— Having thus recognized the acid components, with the exception of the radicals Cl and SO_3, which can only be present to a subordinate extent, we have now to take up the recognition and expression of the bases in the magma. Consequently, Rangs are formed on the chemical characters of the bases in the minerals of the preponderant salic or femic group, according to the Class under consideration. And since there are several of these bases generally present it is necessary to treat them in successive groups. The first and most general division constitutes Rangs.

Subrang.—The comparison of those bases which are united to form the groups of bases recognized in forming Rangs constitutes Subrangs.

Grad.—The characters of the subordinate mineral group, femic or salic, will be treated in a manner analogous to that employed when considering the preponderant, salic or femic, group, the only difference being that as the group under consideration is subordinate fewer distinctions will be needed.

Grads will be based on the general acidic proportions in the minerals of the subordinate group, and will follow the plan of the divisions for Order in the preponderant group.

Subgrad.—These divisions will follow the lines of the subdivisions for Rang and Subrang, and will express the general and special chemical characters of the bases of the minerals of the subordinate mineral group.

Sections.—The application of the above principles shows, however, that in certain points more numerous subdivisions are needed. This necessity is met by the formation of *Sections* of any of the divisions above described. These Sections will be based on more special characters according to circumstances. No general rule can be laid down for them, but they will be explained in their respective places in the subsequent description of the various divisions.

Family and Series.—The grouping of rocks proposed in this system of classification is for the purpose of bringing together rocks that are alike chemically, and also mineralogically and texturally. There is need, however, in the broader treatment of igneous rocks, especially with reference to their genetic relations and to their occurrence in petrographic provinces, to group them in other ways. For these purposes the terms *Family* and *Series* are appropriate, and it is proposed that they be used as follows:

The term *Family* may be applied to a group of rocks that have been developed genetically from a common magma by processes of differentiation. In its broadest sense it may be applied to all the rocks of a petrographic province. But it is

evident that there may be genetic groups of several degrees of consanguinity, for which more specific designations will be necessary. It is suggested that for these groups terms analogous to Family be used.

The term *Series* may be used, in an extension of Brögger's sense,[1] for groups of rocks characterized by similar ratios of certain constituents, as alkalies, but with varying amounts of other constituents, as silica. These series will be of very different characters dependent on the petrographic province, and will have no place in the system proper, since they will traverse it in all directions. They may be designated, as at present, by the use of the names of the extremes, with or without that of an intermediate member.

CLASSES.—It is proposed to divide igneous rocks into five Classes, according to the calculated proportions of the standard mineral groups above defined. As previously stated, these groups are designated as *sal* and *fem* in formulæ, and the descriptive adjectives derived from these are given below.

Class I: $\frac{\text{sal}}{\text{fem}} > \frac{7}{1}$, persalic.

This Class contains rocks *extremely* rich in the salic minerals —quartz, feldspars, feldspathoids, and corundum.

Class II: $\frac{\text{sal}}{\text{fem}} < \frac{7}{1} > \frac{5}{3}$, dosalic.

In the rocks of this Class the salic minerals are *dominant* and the femic minerals *subordinate*.

Class III: $\frac{\text{sal}}{\text{fem}} < \frac{5}{3} > \frac{3}{5}$, salfemic.

In this Class fall the rocks in which the salic and femic minerals are *equal or nearly equal* in amount.

Class IV: $\frac{\text{sal}}{\text{fem}} < \frac{3}{5} > \frac{1}{7}$, dofemic.

[1] *Die Eruptivgesteine des Kristianiagebietes*, Vol. I (1894), p. 169.

The femic minerals are here *dominant* and those of the salic group *subordinate*.

$$\textit{Class V:}\quad \frac{\text{sal}}{\text{fem}} < \frac{1}{7}\text{, perfemic.}$$

The rocks of this Class are extremely rich in the femic minerals—pyroxenes, olivine, magnetite, etc.

SUBCLASSES.—The next step in the systematic subdivision takes account of the distinctions among the standard minerals constituting the salic and femic groups. There being a considerable number of these minerals in each group, it is necessary for reasons already given to divide each group into two parts. Of the salic minerals, quartz, feldspar and the feldspathoids form a closely associated series when considered petrographically and chemically, and may be contrasted with corundum, zircon or other salic minerals. Group I, therefore, falls into Part 1, quartz, feldspars and feldspathoids, indicated in certain abbreviated expressions by the letters Q, F and L, and into Part 2, corundum, zircon, etc., indicated respectively by C and Z.

Group I.
- Part 1. *Quartz* (Q), *Feldspars* (orthoclase, albite and anorthite) (F). *Feldspathoids* (leucite, nephelite, sodalite, noselite) (L).
- Part 2. *Corundum* (C) and *Zircon* (Z).

Similarly, of the femic minerals, the pyroxenes, olivine, akermanite, magnetite, ilmenite and titanite are closely associated in rocks, and form frequent transitional series of rocks with different proportions of these minerals. They may be grouped together as Part 1 of Group II, and contrasted with apatite, fluorite, pyrite, the metals and other femic minerals constituting Part 2. In abbreviated expressions minerals of Part 1 are indicated by the letters P, O and M, those of Part 2 collectively by A.

Group II.
- Part 1. *Pyroxenes* (diopside, hypersthene, wollastonite and acmite) (P). *Olivine* and *akermanite* (O). *Magnetite*, *hematite*, *ilmenite*, *rutile*, *perofskite* and *titanite* (M).
- Part 2. *Apatite*, *fluorite*, *pyrite*, etc. (A).

Subclasses in Classes I, II and III are made on a fivefold basis by considering the relative proportions of the two parts of the salic group, just described. The reasons for using the salic minerals in Class III, instead of the femic, are given in the discussion of Orders. In Classes IV and V Subclasses are formed on the proportions of the two parts of the femic group.

In Classes I, II and III the divisions will be as follows:

Subclass 1: $\frac{QFL}{CZ} > \frac{7}{1}$.

Subclass 2: $\frac{QFL}{CZ} < \frac{7}{1} > \frac{5}{3}$.

Subclass 3: $\frac{QFL}{CZ} < \frac{5}{3} > \frac{3}{5}$.

Subclass 4: $\frac{QFL}{CZ} < \frac{3}{5} > \frac{1}{7}$.

Subclass 5: $\frac{QFL}{CZ} < \frac{1}{7}$.

In Classes IV and V the divisions will be:

Subclass 1: $\frac{POM}{A} > \frac{7}{1}$.

Subclass 2: $\frac{POM}{A} < \frac{7}{1} > \frac{5}{3}$.

Subclass 3: $\frac{POM}{A} < \frac{5}{3} > \frac{3}{5}$.

Subclass 4: $\frac{POM}{A} < \frac{3}{5} > \frac{1}{7}$.

Subclass 5: $\frac{POM}{A} < \frac{1}{7}$.

In the first three classes the distinctions between corundum and zircon may be made in those subclasses in which they are present in notable amount, by the formation of *Sections* as follows:

Section 1: $\frac{C}{Z} > \frac{7}{1}$,

Section 2: $\frac{C}{Z} < \frac{7}{1} > \frac{5}{3}$,

$$\text{Section } 3: \quad \frac{C}{Z} < \frac{5}{3} > \frac{3}{5}.$$

$$\text{Section } 4: \quad \frac{C}{Z} < \frac{3}{5} > \frac{1}{7}.$$

$$\text{Section } 5: \quad \frac{C}{Z} < \frac{1}{7}.$$

In Classes IV and V, Sections may be made analogously, when it is necessary to recognize distinctions between notable amounts of apatite and various metals and sulphides. They need not be given here as the principles controlling them are the same as above.

It will be noted that the vast majority of igneous rocks of all Classes belong to the first Subclass in each Class. There are few rocks known belonging to most of the Subclasses here proposed, but if ever found their classification is thus provided for and will not disturb that of the rocks already known.

In the remainder of this article the classification set forth pertains to Subclasses I of each of the five Classes, unless otherwise stated.

ORDERS.—The division of Subclasses to form *Orders* is made on a basis of the relative proportions of the standard minerals in the preponderant group.

For Classes I and II the preponderant minerals are salic; and in Class III salic minerals are considered before femic, and since minerals of Part 1 are preponderant over those of Part 2 the former are made the basis of subdivision, which is as follows:

a) Quartz, Q.

b) Feldspars (orthoclase, albite, anorthite), F.

c) Feldspathoids (lenads) (leucite, nephelite, sodalite and noselite), L.

Owing to the fact, already discussed, that quartz and the feldspathoids (lenads) are in almost all cases antithetical, so that they do not occur together, these three factors may be employed serially and in the first three Subclasses of Classes I, II and

III the Orders are formed by a double application of the plan of fivefold division, resulting in nine Orders.

Owing to the cumbersomeness of the phrases necessary to describe Orders when the mineralogical group-names are employed quantitatively, it is advisable to use abbreviated terms mnemonic of these mineralogical groups. For these we suggest the following syllables: *quar*, mnemonic of quartz; *fel*, mnemonic of feldspar; *len*, mnemonic of leucite and nephelite, which is understood to include the other standard feldspathoids, sodalite and noselite. From these syllables, with the addition of the proper quantitative prefixes already mentioned, are formed adjectives descriptive of the several Orders as given below.

On account of the resemblance between the words feldspar and feldspathoid, in such frequent use, we suggest for the latter the term *lenad*.

Order 1:	$\frac{Q}{F} > \frac{7}{1}$,	quartz extreme,	perquaric.
Order 2:	$\frac{Q}{F} < \frac{7}{1} > \frac{5}{3}$,	quartz dominant,	doquaric.
Order 3:	$\frac{Q}{F} < \frac{5}{3} > \frac{3}{3}$,	quartz and feldspar equal,	quarfelic.
Order 4:	$\frac{Q}{F} < \frac{3}{5} > \frac{1}{7}$,	feldspar dominant over quartz,	quardofelic.
Order 5:	$\frac{Q \text{ or } L}{F} < \frac{1}{7}$,	feldspar extreme,	perfelic.
Order 6:	$\frac{L}{F} < \frac{3}{5} > \frac{1}{7}$,	feldspar dominant over lenad,	lendofelic.
Order 7:	$\frac{L}{F} < \frac{5}{3} > \frac{3}{5}$,	feldspar and lenad equal,	lenfelic.
Order 8:	$\frac{L}{F} < \frac{7}{1} > \frac{5}{3}$,	lenad dominant,	dolenic.
Order 9:	$\frac{L}{F} > \frac{7}{1}$,	lenad extreme,	perlenic.

It will be noted that in Class III, in which the salic and femic minerals are present in equal or nearly equal proportions,

Orders are established as though the salic minerals were preponderant. This has been done for the reason that both groups of minerals being present in nearly equal amounts, it is necessary to select one group arbitrarily for the basis of division to form *Orders*. Preference is given to the salic group because the greater number of rocks belonging to this class, so far as known, contain slightly more salic minerals than femic, within the range of $\frac{5}{3}$ and $\frac{3}{5}$, Moreover, the present custom of classifying these rocks primarily on a basis of the feldspathic constituents may be allowed to influence the choice. The division of Class III to form *Orders* is therefore the same as those in Classes I and II.

For Classes IV and V the dominant minerals are femic, and the division to form Orders must be based on the relative proportions of minerals of the first Part of this group. They may be grouped into silicates, 1, and non-silicates with titanosilicates, 2. The silicates are further divided into *a*) metasilicates, and *b*) lower silicates, as follows:

1 { *a*) Pyroxenes, diopside, wollastonite, hypersthene, and acmite, P.
  b) Olivine and akermanite, O.

2 Magnetite, hematite, ilmenite, titanite, etc., M.

Orders in these Classes are formed by comparing subgroups 1 and 2, the silicates and non-silicates. For adjectives to describe these Orders we suggest the following syllables mnemonic of the subgroups of femic minerals: *pol*, to indicate pyroxene and olivine with akermanite; *mit*, to indicate magnetite, ilmanite, titantite and the other minerals of this subgroup. For adjectives to describe Sections of Orders, based on a comparison of the two parts of the silicate subgroup we suggest the syllables: *pyr*, denoting the pyroxenes, and *ol*, denoting olivine and akermanite.

Order 1: $\frac{P+O}{M} > \frac{7}{1}$, femic silicate extreme, perpolic.

Order 2: $\frac{P+O}{M} < \frac{7}{1} > \frac{5}{3}$, femic silicate dominant, dopolic.

Order 3: $\frac{P+O}{M} < \frac{5}{3} > \frac{3}{5}$, femic silicate and non-silicate equal, polmitic.

Order 4: $\frac{P+O}{M} < \frac{3}{5} > \frac{1}{7}$, femic non-silicate dominant. domitic,

Order 5: $\frac{P+O}{M} < \frac{1}{7}$, femic non-silicate extreme. permitic.

Sections of Orders.—The division of Orders into Sections is needed in Classes IV and V, to express the relative proportions of the subgroups of the preponderant mineral groups, that is, the proportions between the pyroxene and olivine subgroups.

In Orders 1, 2, and 3 of Classes IV and V, where the polic minerals are extreme, or dominate over, or are equal to the mitic, this division is carried out on a fivefold basis and results as follows:

Section 1: $\frac{P}{O} > \frac{7}{1}$, pyroxene extreme. perpyric,

Section 2: $\frac{P}{O} < \frac{7}{1} > \frac{5}{3}$, pyroxene dominant. dopyric.

Section 3: $\frac{P}{O} < \frac{5}{3} > \frac{3}{5}$, pyroxene and olivine equal. pyrolic.

Section 4: $\frac{P}{O} < \frac{3}{5} > \frac{1}{7}$, olivine dominant. domolic.

Section 5: $\frac{P}{O} < \frac{1}{7}$, olivine extreme. perolic.

SUBORDERS.—In Orders 4 and 5 of Classes IV and V the non-silicate, mitic, minerals preponderate. The subgroups of these minerals, in greatest abundance and most characteristic of rocks belonging to these Orders, contain Fe_2O_3 and TiO_2. The first subgroup includes magnetite and hematite, and is indicated by the symbol H. The second subgroup includes ilmenite, titanite, perofskite and rutile, and is indicated by T. For these subgroups we suggest the syllables *hem* and *til*, mnemonic of the minerals composing then. The relative proportions of these minerals are recognized in Suborders on a fivefold basis, as follows:

Suborder 1: $\frac{H}{T} > \frac{7}{1}$, perhemic.

Suborder 2: $\frac{H}{T} < \frac{7}{1} > \frac{5}{3}$, dohemic.

Suborder 3: $\frac{H}{T} < \frac{5}{3} > \frac{3}{5}$, tilhemic.

Suborder 4: $\frac{H}{T} < \frac{3}{5} > \frac{1}{7}$, dotilic.

Suborder 5: $\frac{H}{T} < \frac{1}{7}$, pertilic.

Rang.—The division for *Rang* is based on the general chemical character of the bases in the minerals of the preponderant group in each *Class*, that is, in the salic or femic minerals used for the formation of *Orders*.

For salic minerals this is expressed by the terms *alkalic* and *calcic*, which relate to the feldspars and lenads. Divisions are based on the proportions of molecules of $K_2O' +$ Na_2O', to CaO' in these minerals, K_2O', Na_2O' and CaO' being the parts of these rock components allotted to salic minerals. The divisions in Classes I, II and III are fivefold:

Rang 1: $\frac{K_2O' + Na_2O'}{CaO'} > \frac{7}{1}$, peralkalic.

Rang 2: $\frac{K_2O' + Na_2O'}{CaO'} < \frac{7}{1} > \frac{5}{3}$, domalkalic.

Rang 3: $\frac{K_2O' + Na_2O'}{CaO'} < \frac{5}{3} > \frac{3}{5}$, alkalicalcic.

Rang 4: $\frac{K_2O' + Na_2O'}{CaO'} < \frac{3}{5} > \frac{1}{7}$, docalcic.

Rang 5: $\frac{K_2O' + Na_2O'}{CaO'} < \frac{1}{7}$, percalcic.

In Order 6, where feldspar is dominant over the lenads, only the first four Rangs will occur, in Order 7 only the first three, in Order 8 only the first two, and in Order 9 only the first one.

For femic minerals the general chemical characters of the bases are commonly expressed by the terms *ferromagnesian*, *calcic*, and *alkalic*. But three independent factors are not to be employed

in this system at one time, and it is necessary to combine two of the three to form a dual basis for a first subdivision. This is accomplished by uniting the first two and comparing the proportions of MgO, FeO, CaO″, and the *alkalies*, K_2O'', Na_2O''. In this case CaO″, K_2O'' and Na_2O'', are the parts of these rock components allotted to femic minerals. For the adjective expressing the first named quality, corresponding to *alkalic*, we propose to use the word *mirlic*, referring to the *m*agnesium, *ir*on and *l*ime. Upon a fivefold basis of comparison of these two sets of chemical constituents we form Rangs of Classes IV and V, although the more alkalic Rangs here provided are not yet known. They are:

Rang 1: $\frac{(Mg, Fe)O + CaO''}{K_2O'' + Na_2O''} > \frac{7}{1}$, permirlic.

Rang 2: $\frac{(Mg, Fe)O + CaO''}{K_2O'' + Na_2O''} < \frac{7}{1} > \frac{5}{3}$, domirlic.

Rang 3: $\frac{(Mg, Fe)O + CaO''}{K_2O'' + Na_2O''} < \frac{5}{3} > \frac{3}{5}$, alkalimirlic.

Rang 4: $\frac{(Mg, Fe)O + CaO''}{K_2O'' + Na_2O''} < \frac{3}{5} > \frac{1}{7}$, domalkalic.

Rang 5: $\frac{(Mg, Fe)O + CaO''}{K_2O'' + Na_2O''} < \frac{1}{7}$, peralkalic.

Sections of Rangs in Classes IV and V are necessary to recognize the varying proportions between the *ferromagnesian* and *calcic* characters of femic minerals, since the magnesium and iron are so closely associated chemically and characterize certain femic minerals free from calcium. For the word ferromagnesian, which is used in a somewhat loose manner in petrography, we propose to introduce the word, *miric*, to indicate strictly the *m*agnesium and *ir*on content in femic minerals, and to be mnemonic of these two metals.

These Sections of Rangs in Classes IV and V have been made on a fivefold basis as follows:

Section 1: $\frac{(Mg, Fe)O}{CaO''} > \frac{7}{1}$, permiric.

Section 2: $\frac{(Mg, Fe)O}{CaO''} < \frac{7}{1} > \frac{5}{3}$, domiric.

Section 3: $\frac{(Mg, Fe)O}{CaO''} < \frac{5}{3} > \frac{3}{5}$, calcimiric.

Section 4: $\frac{(Mg, Fe)O}{CaO''} < \frac{3}{5} > \frac{1}{7}$, docalcic.

Section 5: $\frac{(Mg, Fe)O}{CaO''} < \frac{1}{7}$, percalcic.

SUBRANG.—Subrangs are made on a basis of the special character of the variable or compounded chemical quality used in forming *Rang*. In Classes I, II and III this variable quality is in the ratio of alkalies, potash and soda, and the following subdivisions are recognized for Rangs I, II and III.

Subrang 1: $\frac{K_2O'}{Na_2O'} > \frac{7}{1}$, perpotassic.

Subrang 2: $\frac{K_2O'}{Na_2O'} < \frac{7}{1} > \frac{5}{3}$, dopotassic.

Subrang 3: $\frac{K_2O'}{Na_2O'} < \frac{5}{3} > \frac{3}{5}$, sodipotassic.

Subrang 4: $\frac{K_2O'}{Na_2O'} < \frac{3}{5} > \frac{1}{7}$, dosodic.

Subrang 5: $\frac{K_2O'}{Na_2O'} < \frac{1}{7}$, persodic.

In Rangs IV and V of Classes I, II and III only three divisions are used because of the subordinate amount of alkalies. These Subrangs are:

Subrang 1: $\frac{K_2O'}{Na_2O'} > \frac{5}{3}$, prepotassic.

Subrang 2: $\frac{K_2O'}{Na_2O'} < \frac{5}{3} > \frac{3}{5}$, sodipotassic.

Subrang 3: $\frac{K_2O'}{Na_2O'} < \frac{3}{5}$, presodic.

In Classes IV and V the variable quality is in the miric content. The alkalies are so preponderantly sodic that they do not require subdivision, and no distinction on a basis of the rela-

tive amounts of soda and potash are needed. For the present at least when femic minerals are said to be alkalic, it may be assumed that they are *presodic*. The divisions in Sections 1 and 2 of Rangs I and II are:

Subrang 1: $\frac{MgO}{FeO} > \frac{7}{1}$, permagnesic.

Subrang 2: $\frac{MgO}{FeO} < \frac{7}{1} > \frac{5}{3}$, domagnesic.

Subrang 3: $\frac{MgO}{FeO} < \frac{5}{3} > \frac{3}{5}$, magnesiferrous.

Subrang 4: $\frac{MgO}{FeO} < \frac{3}{5} > \frac{1}{7}$, doferrous.

Subrang 5: $\frac{MgO}{FeO} < \frac{1}{7}$, perferrous.

In Sections 3 of Rangs I and II and in other Rangs of Classes IV and V only *three* divisions are used, because of the subordinate amount of miric component. These are:

Subrang 1: $\frac{MgO}{FeO} > \frac{5}{3}$, premagnesic.

Subrang 2: $\frac{MgO}{FeO} < \frac{5}{3} > \frac{3}{5}$, magnesiferrous.

Subrang 3: $\frac{MgO}{FeO} < \frac{3}{5}$, preferrous.

Sections of Subrangs.—In certain Subrangs a division into Sections is necessary on account of the presence of various acid radicals or for other reasons.

In Classes I, II and III the salic mineral groups, quartz, feldspar and lenads, may be considered as: (*a*) silica and simple silicates, and (*b*) silicates combined with some other salt, or silicates containing some other acid, as Cl and SO_3. The latter are confined wholly to the lenads. This distinction is advisable here, rather than at Suborders, where it might otherwise fall, because of the great change in the mineralogical character of the lenad group induced by the presence of very small amounts of Cl and SO_3 (often less than 1 per cent.

of Cl yielding a notable amount of sodalite), and because, so far as has been observed, or seems *a priori* possible, the minerals of the sodalite group are only present in the sodic or sodipotassic Subrangs of Classes I, II and III. It may be pointed out that the sodalite minerals are also characterized by the presence of more Na_2O than Al_2O_3.

The lenads to be contrasted are the simple silicates, nephelite and leucite, on the one hand, and the more complex silicates, sodalite and noselite, on the other. The former may be designated by the symbols *ne* and *lc*, and the latter by *so* and *no*, and the mnemonic syallables indicating these subgroups are *nel* and *son*.

The division will be needed only in Orders 6, 7, 8 and 9, which contain notable amounts of lenads, and will be fivefold in the sodipotassic, dosodic and persodic Subrangs of the peralkalic, domalkalic and alkalicalcic Rangs.

Section 1: $\frac{\text{ne, lc}}{\text{so, no}} < \frac{7}{1}$, pernelic.

Section 2: $\frac{\text{ne, lc}}{\text{so, no}} < \frac{7}{1} > \frac{5}{3}$, donelic.

Section 3: $\frac{\text{ne, lc}}{\text{so, no}} < \frac{5}{3} > \frac{3}{5}$, sonnelic.

Section 4: $\frac{\text{ne, lc}}{\text{so, no}} < \frac{3}{5} > \frac{1}{7}$, dosonic.

Section 5: $\frac{\text{ne, lc}}{\text{so, no}} < \frac{1}{7}$, personic.

In the dopotassic Subrangs of the Rangs just mentioned, and in the sodipotassic and presodic Subrangs of the docalcic Rangs, the division will be threefold:

Section 1: $\frac{\text{ne, lc}}{\text{so, no}} > \frac{5}{3}$, prenelic.

Section 2: $\frac{\text{lc, ne}}{\text{so, no}} < \frac{5}{3} > \frac{3}{5}$, sonnelic.

Section 3: $\frac{\text{ne, lc}}{\text{so, no}} < \frac{3}{5}$, presonic.

Since we have to deal here with the two acid radicals Cl and SO_3, we may distinguish between the sodalite and noselite rocks by dividing Sections 3, 4 and 5 of the fivefold division above, and Sections 2 and 3 of the threefold, on a threefold basis, which appears to be a sufficient subdivision. These Subsections will be as follows:

Subsection 1: $\frac{Cl}{SO_3} > \frac{5}{3}$, prechloric.

Subsection 2: $\frac{Cl}{SO_3} < \frac{5}{3} > \frac{3}{5}$, chlorsulphic.

Subsection 3: $\frac{Cl}{SO_3} < \frac{3}{5}$. presulphic.

Rocks belonging to each of the five Classes here proposed have been fully characterized mineralogically and chemically, as far as the preponderant salic and femic groups of minerals are concerned. There remains the consideration of the subordinate group, femic or salic, in each case, in order to complete the chemico-mineralogical classification of the rocks.

In Classes I and V since the preponderant group is present in extreme amount, the subordinate group is negligible, and no further division is necessary.

In Class II the subordinate group is present in notable amount, and is femic, while in Class III the femic group is given second place, after salic, so that in both cases we have to do with femic minerals, and further division will take place in this group and will be in general along the lines laid down in the preceding pages in the description of the divisions from Order to Subrang in Classes IV and V.

In Class IV the subordinate group is salic and is present in notable amount, so that further division will take place in this group, following the lines of division from Order to Subrang in Classes I, II and III.

It will furthermore be seen that, since in Classes II and IV the subordinate femic and salic minerals respectively are not equal to the preponderant salic and femic, it will not be necessary in these Classes to make the divisions, at least for the pres-

ent, more than threefold, nor will it be useful to make in all cases the finer distinctions which obtain in the divisions based on the preponderant group of minerals.

In Class III, on the other hand, where the femic minerals are equal to the salic, and may in fact exceed them in some cases, the fivefold subdivision will be employed, and, as far as possible, the distinctions made in the first divisions of Classes IV and V will be recognized.

It may be noted here that it appears that in actual practice these later divisions will be used comparatively seldom in Classes II and IV, and it will be remembered that they do not exist in Classes I and V, but that they become important in the intermediate Class III.

GRADS are based on the proportions of the standard minerals of the subordinate femic and salic groups in Classes II and IV and of the femic group in Class III.

For Class II they are:

Grad 1:	$\frac{P+O}{M} > \frac{5}{3}$,	femic silicate predominant,	prepolic.
Grad 2:	$\frac{P+O}{M} < \frac{5}{3} > \frac{3}{5}$,	femic silicate and non-silicate equal	polmitic.
Grad 3:	$\frac{P+O}{M} < \frac{3}{5}$,	femic non-silicate predominant,	premitic.

In Class III they are:

Grad 1:	$\frac{P+O}{M} > \frac{7}{1}$,	femic silicate extreme,	perpolic.
Grad 2:	$\frac{P+O}{M} < \frac{7}{1} > \frac{5}{3}$,	femic silicate dominant,	dopolic.
Grad 3:	$\frac{P+O}{M} < \frac{5}{3} > \frac{3}{5}$,	femic silicate and non-silicate equal	polmitic.
Grad 4:	$\frac{P+O}{M} < \frac{3}{5} > \frac{1}{7}$,	femic non-silicate dominant,	domitic.
Grad 5:	$\frac{P+O}{M} < \frac{1}{7}$,	femic non-silicate extreme,	permitic.

In Class III it is also necessary to discriminate further between pyroxene and olivine, corresponding to the Suborders of Orders 1, 2 and 3 of Classes IV and V. This will be necessary only in Grads 1, 2 and 3 of Class III. They are:

Section 1:	$\frac{P}{O} > \frac{5}{3}$,	pyroxene predominant,	prepyric.
Section 2:	$\frac{P}{O} < \frac{5}{3} > \frac{3}{5}$,	pyroxene and olivine equal,	pyrolic
Section 3:	$\frac{P}{O} < \frac{3}{5}$,	olivine predominant	preolic.

In Class IV the subordinate minerals belong to the salic group. Their division into Grads is of the same kind as that forming Orders in Classes I, II and III, but since their amount is considerably smaller than in rocks of these Classes, the division is on a threefold basis, resulting in five Grads, as follows:

Grad 1:	$\frac{Q}{F} > \frac{5}{3}$,	quartz predominant,	prequaric.
Grad 2:	$\frac{Q}{F} < \frac{5}{3} > \frac{3}{5}$,	quartz and feldspar equal,	quarfelic.
Grad 3:	$\frac{Q \text{ or } L}{F} < \frac{3}{5}$,	feldspar predominant,	prefelic.
Grad 4:	$\frac{L}{F} < \frac{5}{3} > \frac{3}{5}$,	feldspar and lenads equal,	lenfelic.
Grad 5:	$\frac{L}{F} > \frac{5}{3}$,	lenads predominant,	prelenic.

SUBGRADS are formed on the general chemical character of the bases of the minerals employed to form Grads, and bear the same relation to the latter that Rangs bear to Orders. On account of the smaller amount of the minerals involved in Classes II and IV it is not thought desirable to give the distinctions as great a taxonomic value as when the preponderant minerals are concerned, and so they are made the basis of Subgrads rather than of a new taxonomic division.

In Class II the subordinate minerals being femic the chemical divisions are similar to those forming Rangs in Classes IV

and V, but are on a threefold basis because of the smaller amount of femic minerals, as follows:

Subgrad 1: $\frac{(Mg, Fe)O + CaO''}{K_2O'' + Na_2O''} > \frac{5}{3}$, premirlic.

Subgrad 2: $\frac{(Mg, Fe)O + CaO''}{K_2O'' + Na_2O''} < \frac{5}{3} > \frac{3}{5}$, alkalimirlic.

Subgrad 3: $\frac{(Mg, Fe)O + CaO''}{K_2O'' + Na_2O''} < \frac{3}{5}$, prealkalic.

In Class III Subgrads are formed on a basis of the chemical characters of the femic minerals by analogy with those of Class II, but because of the greater proportions of these minerals the division is on a fivefold basis, yielding:

Subgrad 1: $\frac{(Mg, Fe)O + CaO''}{K_2O'' + Na_2O''} > \frac{7}{1}$, permirlic.

Subgrad 2: $\frac{(Mg, Fe)O + CaO''}{K_2O'' + Na_2O''} < \frac{7}{1} > \frac{5}{3}$, domirlic.

Subgrad 3: $\frac{(Mg, Fe)O + CaO''}{K_2O'' + Na_2O''} < \frac{5}{3} > \frac{3}{5}$, alkalimirlic.

Subgrad 4: $\frac{(Mg, Fe)O + CaO''}{K_2O'' + Na_2O''} < \frac{3}{5} > \frac{1}{7}$, domalkalic.

Subgrad 5: $\frac{(Mg, Fe)O + CaO''}{K_2O'' + Na_2O''} < \frac{1}{7}$, peralkalic.

In Class IV the minerals forming Grads are salic, and since they are subordinate to the femic it is advisable to make only three divisions instead of five, as follows:

Subgrad 1: $\frac{K_2O' + Na_2O'}{CaO'} > \frac{5}{3}$, prealkalic.

Subgrad 2: $\frac{K_2O' + Na_2O'}{CaO'} < \frac{5}{3} > \frac{3}{5}$, alkalicalcic.

Subgrad 3: $\frac{K_2O' + Na_2O'}{CaO'} < \frac{3}{5}$, precalcic.

Sections of Subgrads in Class III are established because the amount of femic minerals is equal or nearly equal to that of the salic, and it is desirable to make further chemical distinctions as in the case of Sections of Rangs in Classes IV and V. The divisions are the same in both cases, and are based on the pro-

portions of miric and calcic constituents. They need only be used in Rangs 1, 2, and 3.

Section 1: $\frac{(Mg, Fe)O}{CaO''} > \frac{5}{3}$, premiric.

Section 2: $\frac{(Mg, Fe)O}{CaO''} < \frac{5}{3} > \frac{3}{5}$, calcimiric.

Section 3: $\frac{(Mg, Fe)O}{CaO''} > \frac{3}{5}$, precalcic.

Subsections of Sections 1 and 2 are based on the proportions of magnesic and ferrous components as in the case of Subrangs in Classes IV and V. They are:

Subsection 1: $\frac{MgO}{FeO} > \frac{5}{3}$, premagnesic.

Subsection 2: $\frac{MgO}{FeO} < \frac{5}{3} > \frac{3}{5}$, magnesiferrous.

Subsection 3: $\frac{MgO}{FeO} < \frac{3}{5}$, preferrous.

It is understood, of course, that all the divisions just described are not needed, as has been explained in regard to those based on the preponderant group of minerals. Thus a calcic Subgrad is not needed in a Grad with dominant lenads. In such cases it is simply inactive.

THE RÔLE OF ACTUAL MINERAL DEVELOPMENT AND TEXTURE IN ROCK CLASSIFICATION.

The methods employed in forming *Classes*, *Orders*, *Rangs*, *Grads*, and their subdivisions are distinctly chemico-mineralogical and chemical, the minerals considered being those defined as *standard*. These divisions are applicable to magmas regardless of their mode of solidification or crystallization. The classification so far is purely magmatic.

The chief object attained up to this point by the system proposed is the uniting of all igneous rocks having like chemical compositions into divisions or groups which conform to our present conceptions of chemical petrographical unity. And it has been our endeavor at the same time to prepare such a

scheme of subdivision that should demands be made for greater chemical discrimination by future petrographers, further subdivision may be carried on as an elaboration of the classification here suggested.

But the problem before us being the classification of igneous rocks, there remains the method of treatment of the rocks themselves. This involves the consideration of the minerals actually present, including the aluminous ferromagnesian minerals, which occur in the great majority of igneous rocks and often form the preponderant constituents. It also involves the consideration of the texture of the rock, which is perhaps the most obvious feature, as well as the legend of its physical history. The elimination of the aluminous ferromagnesian minerals from the system of magmatic classification just described is frankly for its simplification. The exact expression of the chemical magmatic units which would be required should these minerals be introduced would be so intricate as to be practically useless. It is conceivable that an exact mathematical expression involving all of the variable factors or interchangeable combinations, such as are represented by the compositions of biotites, amphiboles, and augites, is possible, but it would be beyond the reach of petrographers generally.

The actual mineral development of an igneous rock is to a great extent so related to the texture that the two are interdependent, which naturally follows from their both being controlled to a large degree by the physical conditions attending eruption and solidification. But since these relations as well as the physical conditions are far from simple, it is therefore necessary, for the present at least, to treat the mineral and textural development of igneous rocks separately.

In petrographical classifications in present use either the actual composition or the texture is made the basis of subdivision, and the other is used for further subdivision. And it is recognized that there is variation in either case within the limits of petrographical divisions, however constituted.

This may be illustrated by the following examples:

1. Let us consider the case of somewhat similar rocks having like textures but somewhat different mineral compositions which have been classed together under one name on a basis of texture, and subsequently separated on a basis of mineral differences, the gabbros. Among several of these rocks with phanerocrystalline granular texture there are those with hornblende, or mica, or olivine, and they are known as hornblende-gabbro, mica-gabbro, and olivine-gabbro.

2. There is a case of a number of rocks having nearly the same mineral composition (labradorite, augite, olivine, and magnetite) and called basalt, which possess quite different textures, such as evenly granular, ophitic, intersertal, porphyritic, or microlitic glassy.

We can see strong grounds for both of these methods of classification, and each may serve an important purpose in petrographical work. There are instances in which one method of correlation is more valuable than another. Freedom of choice should be allowed if consistent with definiteness and stability of the system of classification.

For these reasons the variable characters of each petrographical unit established by the system of classification we propose, which characters are results of the conditions attending solidification, or crystallization, are treated in a different manner from the chemical characters. They are treated as variable factors in the system, although inherent and persistent qualities of a particular rock. They are assigned the rôle of qualifiers of the magmatic units wherever there is need of further subdivision. They consequently appear in the production of a systematic nomenclature, which is an integral part of comprehensive classification.

Actual Mineral Composition.

Let us first consider what minerals may actually be developed in rocks and what relations they bear to the standard minerals which are used to express the chemical composition of a magma unit. And let us assume that the rock is holocrystalline. Those

cases in which more or less of the magma becomes glass will be discussed afterward.

For convenience we introduce two terms which have suggested themselves as substitutes for the cumbrous and oft-repeated expressions, *standard mineral composition* (that calculated from the rock analysis) and *actual mineral composition*. For the first we propose the word *norm*[1], and for the second the word *mode*.[2] The standard minerals which make up the norm are to be called the *normative*[3] minerals, not the *normal* ones, since the latter adjective has the meaning of usual or common.

The questions arise, how far does the *mode* of a holocrystalline rock correspond to the *norm*, and what distinctions are necessary among rocks belonging to one magma unit because of differences among them due to their actual mineral composition?

There are all possible grades of correspondence between the mode and norm of rocks when the whole range of rocks is taken into account, but when this inquiry is applied to separate magmatic units the answer must be modified according to the kind of magma considered.

For example, some magmas of extremely simple composition crystallize in one manner only, so far as our present knowledge goes. Those composed of almost pure silica form only quartz with negligible amounts of other things. Magmas whose norm is quartz and orthoclase will form rocks with these minerals as the *mode*. Magmas whose norm is a simple rock-making mineral, as labradorite or olivine, will crystallize into rocks composed of one of these minerals only.

Consequently rocks belonging to magmatic divisions characterized by extreme amounts of standard quartz, orthoclase, albite or nephelite; of the lime-soda-feldspars; of diopside or hypersthene, or olivine, or magnetite, will have actual mineral compositions very closely corresponding to the calculated norm. That is, the preponderant minerals actually crystallized will be

[1] A rule, pattern, model, authoritative standard.—*Century Dictionary*.

[2] The natural disposition or manner of existence of anything.—*Ibid.*

[3] Establishing or setting up a norm.—*Ibid.*

the same as those calculated from the rock analysis. Variations may occur in the kind of subordinate minerals for reasons which will be explained presently.

On the other hand, magmas containing nearly equal amounts of both salic and femic molecules or dominant amounts of the latter may develop alferric (aluminous ferromagnesian) minerals to such an extent as to prevent the crystallization of any appreciable amount of the standard minerals. A well-known example of this is the hornblendite of Brandberg, in Gran, Norway,[1] a rock of Class III, which crystallized as almost pure hornblende.

A similar magma, however, may crystallize into minerals corresponding closely to the norm, as in the case of the nephelite-basanite of Colfax county, New Mexico.

It follows from this that in some divisions of the system the actual mineral composition of holocrystalline rocks will accord very closely with their norms, while in others it may or may not. And in these cases there may be various degrees of correspondence between the mode and norm.

In general a number of degrees of correspondence between the actual and the standard mineral composition of igneous rocks may be recognized. They may be expressed as follows:

1. COMPLETE OR ALMOST COMPLETE ACCORD BETWEEN THE MODE AND NORM.— In the first case the two correspond exactly both qualitatively and quantitatively. By *almost complete* accord is meant one in which all the principal minerals recognized in establishing the norm are actually present in the rock in approximately the same proportions as in the norm, or else standard minerals not calculated in the norm or non-standard minerals are present in such small amounts as not to affect the position of the rock in the system. In these cases of complete or almost complete accord the rock may be said to have a *normative mode*.

A *normative mode* may be defined as one in which the *actual mineral composition* of the rock is so nearly the same as the *standard mineral composition* calculated from the analysis that either may be used to classify the rock correctly.

[1] *Loc. cit.*

A special and important case of accord between norm and mode is that of the highly feldspathic rocks. It will have been noticed that in the list of standard minerals no reference was made to the plagioclase feldspars intermediate between albite and anorthite (oligoclase, andesine, labradorite, bytownite), nor to the various alkali-feldspars, other than orthoclase and albite, such as microcline and soda-microcline (anorthoclase). This is for the following reasons :

The feldspars present in a rock are seldom of only one kind, several distinct species being present usually, this being true especially of the plagioclases.

The individual plagioclase crystals are frequently zonal, so that an exact determination of the relative amounts is a matter of difficulty if not of impossibility.

When orthoclase, albite and anorthite molecules are present, in rocks of identical chemical composition, the possibilities of combination of these as actual minerals are many. Thus we may have an orthoclase-andesine rock, in which all the albite has crystallized with the anorthite, or an anorthoclase-labradorite rock, where some of the albite has crystallized with the orthoclase.

We therefore classify rocks, as far as the feldspars are concerned, by the calculated molecules of orthoclase, albite and anorthite, irrespective of their actual mineral combinations. The proportions of these will give the *mean composition* of the feldspars. Any of the possible combinations will then be *normative* in the sense above, provided that none or only a negligible amount of the feldspathic molecules crystallize as lenads.

If it should be desired to indicate in the name which combination is actually present, this can be done by the use of the appropriate feldspar name, as described later. Since, however, the albite molecules crystallize with those of anorthite, if these are present in any quantity, it will be necessary to distinguish only the cases in which the albite molecule has crystallized with that of orthoclase, as soda-orthoclase.

2. Appreciable difference between the norm and mode. —Abnormative minerals (whether standard or not) are in such

cases present in quantities which are not negligible, so that the rock cannot be classified directly from the minerals actually present without consideration of the mutual changes involved in the diverse crystallization of the various minerals possible. Such modes may be called *abnormative*.

The abnormative modes may be referred to two kinds, of which the second is by far the most important and common, though the first naturally precedes it in the discussion.

a) The minerals present may be all standard, but differ from those of the norm either in kind or relative proportions, or both. This case is generally due to shifting of the SiO_2 and TiO_2, and may be illustrated by these instances: quartz and leucite crystallize instead of orthoclase, albite instead of nephelite with leucite, as in leucite-basanites and tephrites, quartz with olivine as in quartz-basalts, hypersthene with nephelite, titanite instead of perofskite or ilmenite, the silica in this case coming from normative feldspar molecules. The normative corundum may also form muscovite with molecules of orthoclase and water.

These cases, it will be seen, affect the mineral molecules of oxides capable of combining in more than one proportion with SiO_2, namely K_2O, Na_2O, $(Fe,Mg)O$. All of these modifications are within the range of the standard salic and femic minerals, and if not accompanied by notable amounts of non-standard minerals (as augite or hornblende), may be called respectively *salic*, *femic*, or *salfemic* abnormative modes, according as the abnormative minerals belong to one or the other or both groups.

b) The mode may differ from the norm through the presence of alferric (aluminous ferromagnesian) minerals, augite, hornblende, biotite, garnet, etc.

As is explained in the Part on Calculation, and as is evident on consideration of the subject, the formation of any of these minerals involves changes in some, if not all, of the standard minerals calculated as present in the norm. While minerals of both the standard salic and femic, and non-standard alferric groups are involved, yet it will be sufficient to characterize these modes as *alferric*.

In both the above cases *a* and *b* it is evident that, given the knowledge of the norm and the mutual interrelations between the rock-making minerals which will be explained in the Part on Calculation, it is only necessary to know the amount of abnormative minerals, whether standard or not, to be able to ascertain the changes from the norm which their presence involves. These distinguishing minerals therefore may be called *critical* ones.

The question of how far quantitative distinctions based on the amounts of the critical minerals are to be introduced into the classification is discussed in connection with the nomenclature.

Having thus explained the various relations possible between norm and mode, it will be well to summarize the correspondence observed in fact among the different Classes. It is obvious that no one systematic method of calculation of mineral composition from the chemical can correspond with all the varying possibilities of actual mineral development. The method adopted by us, however, being founded on the most frequently observed mineral relations in igneous rock and on the most generally applicable principles, should yield norms which correspond with the mode in the majority of cases.

This is a point which can only be tested by appeal to the literature of petrography, and comparison of the calculated norms with the modes as furnished by the descriptions. We have, it may be stated here, tested our proposed method in regard to this point very thoroughly upon many hundreds of rock analyses, and especially by means of a collection made by one of us (H. S. W.) of all analyses of igneous rocks which have been published since 1883, amounting to over three thousand.[1]

This comparison shows that the accord between norm and mode is complete or nearly so in the very great majority of

[1] It is hoped that this collection, which will show the norm in every reliable case, will appear shortly after the publication of the present paper, and it will serve as a general illustration of the system. Although not as yet available to others, it has been appealed to as a practical check throughout our discussions, so that the system cannot be regarded as merely academic, but as having been tested at every possible point.

rocks of Class I and in the greater portion of those of Class II, these two classes comprising over three-quarters of the known or analyzed igneous rocks of the globe. The accord is also very good in Class V, which includes but few rocks. Classes III and IV show less constant accord, as is to be expected in view of their composition. The results of our proposed method of calculation may therefore be regarded as satisfactory.

VARIETIES.— It is evident that within the range of possible variations in each of these modes for a given magma unit, there may be mineralogical distinctions among the quite subordinate components, and that it may be desirable to recognize these differences as distinguishing features of rocks. The method of accomplishing this is by considering the several subdivisions upon this basis as *Varieties*, more specifically *Modal Varieties*.

A *Modal Variety* of a petrographical unit of whatever degree, such as Class, Order, Rang, etc., may be defined as a rock having a mode with a slightly different development of the quite subordinate component minerals.

For example, a rock belonging to Class I composed of an extreme amount of feldspar (5th Order) may have 10 per cent. of nephelite actually crystallized, whereas the norm contains no nephelite, the difference having been brought about by the development of a small amount of hypersthene or of hornblende instead of olivine.

The development of a small amount of hornblende, or of biotite, in a rock with a normative mode also constitutes a Modal Variety. The presence of small (not notable) amounts of rare or otherwise noteworthy minerals may also thus be recognized as varieties.

Indeterminable Modes.— Rocks not completely crystallized, containing glass base, and those which for any reason do not permit the determination of all the component minerals, must be classified in the first instance in each case by comparison of the observed minerals with the norm calculated from the chemical analysis of the rock, and subsequently, by analogy with holocrystalline rocks of similar chemical composition whose texture

is somewhat like that of the rock in question and whose actual mineral components can all be determined.

Texture.

The terms *structure* and *texture* are commonly used in petrography as synonyms, although efforts have been made to discriminate between them. It seems to us desirable to employ them in different senses, and we propose to limit the use of the term *structure* to those large features of rock bodies which are known as columnar structure, spheroidal parting, platy parting, bedding, brecciation and others. And we use *texture* for the material features of rocks exhibited by the mineral components and by the groundmass of dense or glassy rocks, whether they are viewed megascopically or microscopically. These features are the expression of the mutual relations of the mineral particles or vitreous portions of rocks.

The texture of igneous rocks is one of their most variable characters. It depends in very large degree upon extraneous conditions influencing the consolidation of the magma and in far less degree upon certain relationships between the forms of the rock-making minerals. The factors influencing it are many. Nearly the whole range of textures may be developed in rocks from a single magma consolidating under different conditions. Consequently the use of texture as a primary factor in the classification of igneous rocks can only result in the wide separation of things alike in chemical and mineral characters, which, on the grounds discussed in the preceding pages, are believed to be of greatest systematic importance.

Its use as a prominent factor in classifications has been in most cases coupled with assumptions or assertions known to be by no means strictly in accordance with facts. When such a use of texture is to be made, it is necessary to assume that all rocks possess some one of the few textures at present employed in classification, such as the granular, porphyritic, trachytoid, glassy, etc. This further requires that these textures be so broadly defined that they are robbed of much of their natural

descriptive value, or that the definitions be so restricted that they are not appropriate to many of the rocks to be classified.

It has been common to assume a fictitious dependence of texture upon geological occurrence, ignoring other conditions which are plainly of much influence; as, for example, the assumption that granular rocks are plutonic or deep-seated, or, from the converse point of view, that effusive rocks must be partially glassy, or trachytic, or porphyritic.

Less often definitions of texture have involved assumptions of their origin only partially in accord with the facts.

In some cases rocks have been classified on a basis of only part of their texture, as when in certain porphyritic rocks the texture of the groundmass alone has been taken into consideration.

It appear to us that the use of texture in previous petrographic classifications has, on the one hand, weakened the systems by rendering them unnecessarily artificial and illogical, and, on the other hand, has prevented the natural application of certain textural terms. The classificatory rôle assigned to texture in this system is that of a qualifier of any of the various divisions based upon chemical and mineral characters. We present certain general considerations of rock textures which may aid in securing for the various factors which enter into texture a recognition which it seems to us they have not thus far commonly secured. The discussion does not profess to be complete as to all rock textures but simply takes up some of the more prominent textures and discusses their essential properties and relations.

When we consider the texture of igneous rocks we find that it may be separated into three factors, which though not in all cases absolutely distinct from one another are so to a very considerable extent. They are:

I. *Crystallinity.* The degree of crystallization.

II. *Granularity.* The magnitude of the crystals.

III. *Fabric.* The shape and arrangement of the crystalline and non-crystalline parts.

Various textural modifications of igneous rocks may be distinguished from one another, but it is understood that in this respect, as in all others, there are all gradations between different textures. Moreover, all known textures are not developed within every known magma unit, and some textures are specially frequent in rocks of particular compositions.

I. Crystallinity.—The degree of crystallization attained by an igneous rock is measured by the relative amounts of crystallized and glassy portions. Perfectly glassy rocks are very uncommon, since most obsidians abound in microscopic crystals, while many lavas that are almost completely crystallized contain small amounts of glass. Most rocks are holocrystalline, and all gradations between the extremes exist.

Distinctions that have been based on crystallinity are of two sorts: one an absolute distinction based on the known absence or presence of glass base or matrix, resulting in (*a*) *holocrystalline*, (*b*) *hypocrystalline, or partly crystalline*, and (*c*) *holohyaline, or completely glassy*, rocks. The other sort of distinctions are less definite, being based on the megascopic appearance of the rock, but they are of great practical value. They are (*a*) *phanerocrystalline*, (*b*) *aphanitic*, and (*c*) *vitreous*.

Phanerocrystalline rocks are generally *holocrystalline*.

Aphanitic rocks are in some instances microscopically *holocrystalline*, in others *hypocrystalline*. Because in some cases it is not possible without microscopical study to determine the presence or absence of glass matrix, it is extremely useful to refer a rock to this textural division. It is discussed again in the next phase of the subject.

Vitreous rocks are *hypohyaline* or *holohyaline*.

II. Granularity is the quality based on the absolute size of the crystals, which, when all igneous rocks are considered, range from microscopic sizes to megascopic ones measured in feet. The quality derived from the relative sizes of the crystals in one rock may be considered as a phase either of granularity or of fabric.

Distinctions based on differences in the absolute size of the

grain of rocks have never been sharply defined, because the crystals in an igneous rock are never of uniform size. They vary among themselves considerably in most cases, and it is the average size which is in mind when reference is made to the grain of a rock.

The most important distinction made on this basis is for practical purposes, namely, that between *phanerocrystalline* (phaneric) rocks, whose crystals may be seen by the unaided eye, and *aphanitic* or *cryptocrystalline* rocks, whose crystals are not apparent megascopically. The term *aphanitic* is the better one to use in most cases, because the term cryptocrystalline implies the holocrystalline character of the rock, which may not have been determined. This fact is well expressed by the negative term aphanitic.

Phaneric (phanerocrystalline) rocks are commonly divided into *coarse-grained*, *medium-grained*, and *fine-grained*. But for these terms no limits have been set except those suggested by Zirkel,[1] namely, that the first include all those whose average grain is larger than the size of peas; that the second range from the size of peas to that of millet seeds; and that fine-grain include those of the size of millet seeds and smaller. Translating this into millimeters we would suggest the following scale:

Fine-grained rocks, average grain 1 millimeter or less.

Medium-grained rocks, average grain 1 to 5 millimeters.

Coarse-grained rocks, grain more than 5 millimeters.

Aphanitic rocks have never been systematically divided on a basis of the size of the microscopic crystals, though terms borrowed from the megascopical nomenclature have been adopted to fit the case. These are: *microcrystalline*, which is equivalent to microphanerocrystalline, and applies to textures whose grains can be seen with a microscope; and *microcryptocrystalline*, which includes textures whose grains cannot be seen with a microscope, but which are recognized as present by the exhibition of aggregate polarization between crossed nicols.

In place of distinctions corresponding to coarse, medium,

[1] *Lehrbuch der Petrographie*, Vol. I, p. 456, 1893.

and fine-grain, which are useful when megascopically applied, it is possible to describe the average measured diameter of microscopic crystals. But there appears to be no demand for systematic subdivisions based on the magnitude of these minute textures.

Textural distinctions based on the relative sizes of the crystals in one rock recognize (1) *evenly granular* or *non-porphyritic* rocks, and (2) *porphyritic* rocks. These distinctions cannot be sharply drawn, because, as already said, it almost never happens that all crystals in a rock are the same size. Moreover, there is a great variety of ways in which differences of size in crystals may exhibit themselves.

The difference of size which constitutes *porphyritic* texture may be defined as that in which the size of some crystals is so much larger than that of a sufficient number to form a matrix for the first, that the larger ones appear notably distinct from the matrix or groundmass. There are *porphyritic* rocks with phaneric (phanerocrystalline), aphanitic, or glassy, groundmasses, the phenocrysts being megascopically notable. And there are microporphyritic aphanitic or glassy rocks, in which the phenocrysts are not megascopically notable, although they may be visible.

Granular and porphyritic textures may also be considered as modifications of the fabric.

III. Fabric.—The *arrangement of the crystalline* and *noncrystalline* parts of a rock, or its *fabric*, as we propose to call it, is dependent on (1) the shapes of the crystals, and (2) their positions with respect to one another and to the glass base when present.

When considered with reference to all the minerals in the rock the fabric of most rocks is so complex that no simple expression is applicable to it, and nearly all the formal relations which it is customary to distinguish as different rock textures frequently exist in one rock. However, it usually happens that certain features dominate in each case while others may be quite insignificant though present. Hence we may again disregard

those which do not occur to a notable extent and use those which predominate as the means of discrimination, that is, as a basis for textural subdivision.

1. As to the shape of the constituent crystals, there are two distinctions of a general nature:

(*a*) *Automorphic*[1] (idiomorphic) forms, in which the crystal form has been developed more or less perfectly.

(*b*) *Xenomorphic*[1] (allotriomorphic) forms, in which the proper crystal form has not been developed owing to interference from outside influences.

These latter forms are of two kinds: one caused by the interference of adjacent crystals, the commonly recognized case in holocrystalline rocks; the other is caused by outward forces acting in the liquid from which crystallization has taken place, which produce irregularly shaped crystals peculiar to microscopic growths in the more siliceous glasses, but not confined to them.

Other distinctions of shape depend on the particular forms of the crystals, whether equidimensional, tabular, prismatic, or otherwise.

2. The arrangements or positions of crystals with respect to one another may be grouped under several heads:

A. *Juxtaposition.*—In this case, although subordinate minerals may be enclosed in the preponderant ones, the preponderant minerals are adjacent to one another, and the following divisions based on the shape of the crystals are recognized:

Granular, in which adjacent crystals have nearly the same size, so that the rock appears to be made up of more or less uniform grains. According to the form of the individual crystals the rock is said to be:

a) *Xenomorphic granular*, in which the crystals are xenomorphic and equidimensional. This is commonly called "granitic" fabric.

[1] We adopt the use of *automorphic* and *xenomorphic* instead of *idiomorphic* and *allotriomorphic*, as they have undoubted priority, Rohrbach having used the former in 1886 (*T. M. P. M.*, Vol. VII, p. 88), while Rosenbusch introduced the latter terms in 1887. Rohrbach's terms have the further advantage of being shorter.

b) *Hypautomorphic granular*, in which some of the crystals, or parts of some crystals, are automorphic, while others are xenomorphic.

c) *Panautomorphic granular*, in which all the crystals possess their proper forms more or less perfectly. Of course absolute automorphism cannot exist in a compact, continuous rock. The precise character of this fabric depends on the kinds of minerals present and on their particular habit. It is, therefore, different in rocks of different compositions so far as observed.

Tabular or prismatic fabric.—There is further modification of it in case the shapes of some of the minerals are *tabular* or *prismatic*. In such cases there may be distinctions according as there is: no definite arrangement of plates or prisms, which stand in all positions; or a regular arrangement in more or less parallel directions (*fluidal* or *parallel fabric*), or in more or less radiatng directions (*radiate fabric*).

B. *Interposition* (inclusion).—The arrangements of crystals referred mainly to inclusion of one by another are of two principal kinds:

a) *Graphic fabric.*—One in which two minerals mutually inclose one another, by interpenetration. This is shown by the parallel orientation of several parts of each mineral. The familiar example is the *graphic* intergrowth of quartz and feldspar.

b) *Poikilitic fabric.*—The second kind of interposition fabric is that in which one mineral acts as a matrix for one or more kinds of other minerals which do not possess parallel orientation. This is exhibited by various rocks, in some of which hornblende crystals form the matrix, in others orthoclase, in others quartz.

Ophitic fabric is a special case of poikilitic, in which plagioclases are inclosed in augite crystals, the feldspars being relatively large when compared with the areas of augite.

C. *Porphyritic fabric* is one characterized by the presence of crystals surrounded by a matrix noticeably distinct from them. These crystals are known as *phenocrysts*. The matrix or groundmass may be crystalline or glassy. The phenocrysts

are megascopic in some cases, and microscopic in others. When they are microscopic in a glassy matrix the fabric is called *microlitic glassy*.

D. *Orbicular fabrics.*—There are complex fabrics so frequent and so characteristic that they have formed bases for textural divisions. They are:

a) *Spherulitic*, allied to the microlitic fabric in some cases in that it can be traced to special forms of microscopic crystallization, consisting of radiating prisms. It is further allied to porphyritic fabric, in that it may be developed locally in the magma and produce scattered spherulites of notable size, and having the appearance of phenocrysts.

b) *Spheroidal*, closely like spherulitic in some cases, where there is crude radial arrangement of crystals, but quite different from it in others in which there are concentric granular shells. A somewhat diverse form of aggregate crystallization occasionally developed in phaneric rocks.

HETEROGENEOUS TEXTURES produced by more or less heterogeneity in the magma are distinguished by marked variability of (*a*) fabric, or (*b*) composition.

a) *Eutaxitic texture.*—Variability of fabric is exhibited by some banded or streaked lavas (rhyolites) in which alternate layers of rock exhibit different degrees of crystallinity or different arrangements of crystals. Variability of texture on a large scale is often exhibited by phaneric rocks of similar composition (granitic pegmatites).

b) Variability of composition may not strictly belong to the discussion of the texture of rock, but the two are intimately blended, and the treatment of the matter in this place may be justified. It results in *banded textures*, approaching gneissic, and is exhibited in certain gabbros; also in irregularly streaked textures, known in German as *Schlieren*, which may be called *schlieric textures*.

In classifying rocks on a basis of textural differences we have considered the fabric, or the shape and arrangement of the crystals, as more fundamental than the crystallinity or granularity,

for the reason that it is more clearly a function of the composition of the magma, since it depends upon the shapes of the crystals which are often characteristic of particular minerals which preponderate in rocks of certain compositions.

On the other hand it is possible for any magma to attain any degree of crystallinity, although all degrees, from glassy to holocrystalline, are not known for all kinds of magmas. In the same way any magma may develop any grade of granularity, although some grades are oftener observed in certain kinds of magmas than in others.

The method of recognizing these differences of texture and of introducing them into the classification is referred to the nomenclature, where it will be fully stated.

PART II. NOMENCLATURE.

Having outlined the system of classification proposed by us, it is necessary to present and discuss the nomenclature which we have constructed for its expression and use.

As already pointed out, the present system of nomenclature is most unsatisfactory, for the reasons that it furnishes no distinctions between names of different values (one termination alone being regularly used), nor indication of the relations of any of the groups.

Furthermore, since the system of classification here proposed is based on relations and principles quite distinct from those in present use, the old names cannot be employed for the new divisions. This is obvious for the reason that the new divisions do not cover the same concepts or characters as the old ones, and because the use of an old name with a new meaning is to be shunned as leading to grave misunderstanding and confusion.

Rock names, like those of any other system of nomenclature, are, or should be, composed of two parts, with distinct functions, viz., the *body* or *root*, and the *termination*. The former expresses either directly, or by implication or connotation, the character of the object or group of objects to which it is applied, and the latter indicates the place of the object or group in the co-ordi-

nated system, from the broadest to the smallest division. Each separate division, from the largest to the smallest, should have a distinctive appellation, precluding confusion with others, and indicating at once its relative place in this system and its character. The names should be mnemonic, if possible, expressing the idea to be conveyed, short, euphonious, and not liable to be mistaken for one another.

In accordance with the principles just stated, we have constructed names for the various magmatic divisions which have been explained in the preceding pages on classification. In addition to these it will be necessary to employ qualificatory terms to express the variable characters of mineral composition and texture, which, with the appropriate magmatic name, will apply to the rocks themselves. The nomenclature, then, will be to a certain extent polynomial. These qualifiers may be applied at any point in the system.

MAGMATIC NAMES.

TERMINATION.—It is possible to indicate the place of any given rock name in a system by employing only one termination and by varying the root of the word, which then alone indicates at the same time both the character of the group and its relative position in the system. Thus, with the single termination *-ite* the family name, foyaite, expresses the concept of rocks formed essentially of alkali-feldspar and nephelite, while smaller divisions of this are indicated by such names as laurdalite, litchfieldite and lujavrite.

But this method is very unsatisfactory and primitive, in that it does not avail itself of the very powerful aid afforded by such possible terminations as would in themselves give considerable knowledge of the group named. Furthermore, while feasible with a small number of names, such a method involves a great tax on the memory, especially with the rapid growth of our knowledge of rocks and of new rock types, and the necessity for new names.

These serious objections to the use of but one termination

have so far been scarcely recognized, and this great defect in present nomenclature is one cause of much of the prevalent outcry against the multiplication of rock names.

To indicate the relative place of the various divisions in the system, from Class to Subgrad, we have adopted a set of terminations which are to be used invariably with their respective divisions. We have endeavored to select those which are at the same time: mnemonic in suggesting the relative positions of the divisions; euphonious; not in previous use to any great extent; and as far as possible adapted to use in all European languages. The termination -ite is rejected because it is already in use, not only in petrography but in mineralogy, to which latter science, as having a prior claim, we suggest that it be restricted. The terminations proposed are as follows:

Class,	-ane.	Subclass.	-one.
Order,	-are.	Suborder,	-ore.
Rang,	-ase.	Subrang,	-ose.
Grad,	-ate.	Subgrad,	-ote.

These terminations were selected after trial of many that were suggested. The distinctive consonants, *n*, *r*, *s*, *t*, are in their alphabetical order, suggesting the sequence of the taxonomic divisions to which they refer. The vowels, *a* and *o*, were considered best to indicate the distinctions between each principal division and its subdivisions. And the final *e* is added in English to lengthen the sound of these vowels, but it may be omitted when the words are used in other languages.

The name of a magma belonging to a *Section* of any given division will receive the termination of that particular division preceded by the letter *i*, since it occupies the same relative position in the scheme as the division in question, although of somewhat different taxonomic character.

Root.—In choosing the root of the name two methods are available. This part may be a syllable or syllables derived from local or personal names or chosen arbitrarily, giving only by connotation an idea of the character of the group named; or it may be composed of syllables which will of themselves, by

proper selection on mnemonic grounds, give an idea of t h character.

The latter method would seem at first sight to be the better, since it apparently involves less tax on the memory. We have, however, made many attempts at the construction of such name roots, giving them practical trials at all points of the scheme, but have been forced to reject this method for all divisions except that of Class, for the following reasons :

1. The names are apt to be excessively long and cumbrous, especially in the smaller divisions.

2. While the distinctions can be readily seen on paper, yet close attention must be paid to each syllable and even to each letter, and in spoken language the names are so similar as to be confused with each other.

3. As a consequence, the mnemonic quality, which is the great theoretical advantage of this method, is very seriously diminished, especially in the smaller divisions.

4. The adoption of this method involves a fixation or lack of elasticity in the nomenclature, which would be fatal to it, if the need arose for any change either in the method of arriving at the divisions or in their number, since this would involve a corresponding change in the nomenclature.

We have, therefore, except for Classes and Subclasses, adopted roots derived from names of localities, taking advantage of the fact that there are at present many of these in present petrographical nomenclature with connoted magmatic ideas which are readily adaptable to our purpose. Thus with the root *nordmark* is connoted the idea of an alkali-feldspathic rock, with *miask* that of a rock composed essentially of alkalifeldspar and nephelite. These are, it is true, not the only connotations of these names, since in both of them are also implied ideas of texture.

In the names suggested subsequently we have endeavored to adhere to the following principles in the selection of roots.

a) They should be adjusted to the relative position of the divisions to which they are applied. That is, the roots of names

which are at present in use for large rock groups, or which were proposed by the author for such groups, are used for the larger divisions, such as Rangs, while those which have at present, or were originally given, narrower or more specific character or application, are used for the smaller divisions, Subrangs, Grads, and Subgrads.

Inasmuch as few if any of the rock names at present in use, even the broadest, cover the wide mineralogical concepts involved in our proposed Orders, and as it will also be well to make the names of these broad groups quite distinctive, we have adopted as the source of the roots for Orders the names of countries. We have endeavored to select in each case the name of a country where the respective Order is found in especial abundance or is most typically represented, or which is historically connected with the Order. This is, of course, not possible in every case, as some of the most abundant Orders are represented in several countries. In such cases we have endeavored to apportion the ordinal roots equitably among the petrographically prominent nations.

b) The selection should be based on rocks of which good analyses exist. This is obviously just, since a poor analysis is of little use, and is often of positive harm, to the science and to any system of classification, and furthermore it will frequently happen that a name based on such will prove eventually to have been misapplied.

c) A locality root already in use should be employed if possible.

d) As far as is consistent with the preceding principles, the laws of priority will hold good, as usually recognized and as formulated in Dana's *System of Mineralogy*.

e) In selecting a new root from several possible localities, the one should be chosen which is best known, has been best described, or which furnishes the most typical material.

f) The roots should be short, if possible not more than two syllables, and euphonious.

g) The name of a locality where the mode is normative is to be employed if possible.

h) As far as possible localities whose rocks occur near the classificatory borders of a given group are to be avoided.

Intermediate magmatic names.—A rock, whose composition is such that its magma occurs so near the border line of any division of the system as to be considered a transition magma, receives a compound magma name, made by uniting the names of the two divisions concerned, and connecting them with a hyphen. The name of the division in which the rock occurs is to be preceded by that of the neighboring division.

NAMES.—As the Classes are few in number the strictly mnemonic method of root-formation is applicable to them, and we have accordingly named them on the basis of the relative amounts of the standard salic and femic minerals present, these being indicated by the syllables *sal* and *fem*, as already explained. The relative amounts are shown by the prefixes *per-* and *do-*, which stand respectively for *extremely abundant* and *dominant.* The names for the five classes are as follows :

1. Persalane : Extremely salic—$\frac{\text{Sal}}{\text{Fem}} > \frac{7}{1}$.

2. Dosalane : Dominantly salic—$\frac{\text{Sal}}{\text{Fem}} < \frac{7}{1} > \frac{5}{3}$.

3. Salfemane : Equally salic and femic—$\frac{\text{Sal}}{\text{Fem}} < \frac{5}{3} > \frac{3}{5}$.

4. Dofemane : Dominantly femic—$\frac{\text{Sal}}{\text{Fem}} < \frac{3}{5} > \frac{1}{7}$.

5. Perfemane : Extremely femic—$\frac{\text{Sal}}{\text{Fem}} < \frac{1}{7}$.

For other magma units names derived from geographical localities have been used, as already explained. Those suggested by us apply to the more important divisions of the system, and to those based on the best established data, derived from the collection of several thousand analyses already referred to, and from older analyses where available. There are numerous divisions for which we have not sufficient data to warrant our suggesting names at this time. Owing to the large number of names selected, they are presented in tabulated form, in such manner that they can be understood without difficulty.

A list of all new words proposed by us, with their definitions, will be found in a Glossary which will appear with a reprint of this essay, to be published in book form by the University of Chicago Press. The Glossary and the Tables to aid the calculation of norms are too voluminous to be printed in this JOURNAL.

ROCK NAMES.

As just explained, the names to be applied to the systematic divisions, or magma units, are formed from names of geographical localities modified by a series of terminations, and designate rocks so far as their chemical composition and standard mineral composition are concerned, but do not indicate their actual mineral composition or their texture. The methods of expressing these latter characters in the systematic nomenclature remain to be stated. As already said, each is treated independently of the other. We take up first the expression of the actual mineral composition.

ACTUAL MINERAL COMPOSITION.—A nomenclature that will express the mode of a rock must indicate the kinds of minerals present and their quantity. The question then arises: How far is it necessary to modify, or qualify, the magmatic names in order to accomplish this, and further: What exactness is desirable in expressing the quantity of the actual minerals present?

When the name of the magma unit to which a rock belongs is given, there is implied in it the standard mineral composition, or *norm*, and in order to describe the actual mineral composition, or *mode*, of the rock it is only necessary to state the extent to which this differs from the norm.

And since quantitative distinctions within a petrographical unit of the smallest magmatic division established by this system would further subdivide these units, it does not appear desirable in the present state of petrographical science to carry such subdivision to any considerable extent, however desirable it may become in the future.

If the mode be *normative*, that is, if there be complete or almost complete accord between the standard mineral composi-

	E.	$8, \frac{L}{F} < \frac{7}{1} > \frac{5}{3}$ ONTARARE.	$9. \frac{L}{F} > \frac{7}{1}$ x
RANG 1, PERALK,		1	1
Subrang 1,			
Subrang 2,			
Subrang 3,			
Subrang 4,			
Subrang 5,			
RANG 2, DOMAI			
Subrang 1,			
Subrang 2,			
Subrang 3,			
Subrang 4,			
Subrang 5,			
RANG 3, ALKAI			
Subrang 1,			
Subrang 2,			
Subrang 3,			
Subrang 4,			
Subrang 5,			
RANG 4, DOCAL			
Subrang 1,			
Subrang 2,			
Subrang 3,			
RANG 5, PERCAL			

NOTE.—X indica

CLASS I, PERSALANE, $\frac{SAL}{FEM} > \frac{7}{1}$. SUBCLASS I, PERSALONE, $\frac{QFL}{CZ} > \frac{7}{1}$.

ORDER	1, $\frac{Q}{F} > \frac{7}{1}$ VICTORARE.	2, $\frac{Q}{F} < \frac{7}{1} > \frac{5}{3}$ *BELGARE.*	3, $\frac{Q}{F} < \frac{5}{3} > \frac{3}{5}$ COLUMBARE.	4, $\frac{Q}{F} < \frac{3}{5} > \frac{1}{7}$ BRITANNARE.	5, $\frac{Q,\ L}{F} < \frac{1}{7}$ CANADARE.	6, $\frac{L}{F} < \frac{3}{5} > \frac{1}{7}$ RUSSARE.	7, $\frac{L}{F} < \frac{5}{3} > \frac{3}{5}$ TASMANARE.	8, $\frac{L}{F} < \frac{7}{1} > \frac{5}{3}$ ONTARARE.	9, $\frac{L}{F} > \frac{7}{1}$ x
RANG 1, PERALKALIC, $\frac{K_2O + Na_2O}{CaO} > \frac{7}{1}$		1. *Dargase*	1. *Alaskase*	1. *Liparase*	1. *Nordmarkase*	1. *Miaskase*	1. *Laugenase*	1	1
Subrang 1, Perpotassic, $\frac{K_2O}{Na_2O} > \frac{7}{1}$			1. x	1. Lebachose	1	1	1		
Subrang 2, Dopotassic, $\frac{K_2O}{Na_2O} < \frac{7}{1} > \frac{5}{3}$			2. Magdeburgose	2. Omeose	2	2	2		
Subrang 3, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$			3. Alaskose	3. Liparose	3. Phlegrose	3. Beemerose	3. x		
Subrang 4, Dosodic, $\frac{K_2O}{Na_2O} < \frac{3}{5} > \frac{1}{7}$			4. x	4. Kallerudose	4. Nordmarkose	4. Miaskose	4. Laugenose		
Subrang 5, Persodic, $\frac{K_2O}{Na_2O} < \frac{1}{7}$			5. Westphalose	5. Noyangose	5. Tuolumnose	5. Mariupolose	5		
RANG 2, DOMALKALIC, $\frac{K_2O + Na_2O}{CaO} < \frac{7}{1} > \frac{5}{3}$		2. x	2. *Alsbachase*	2. *Toscanase*	2. *Pulaskase*	2. *Viezzenase*			
Subrang 1, Perpotassic, $\frac{K_2O}{Na_2O} > \frac{7}{1}$		1. x	1	1	1	1			
Subrang 2, Dopotassic, $\frac{K_2O}{Na_2O} < \frac{7}{1} > \frac{5}{3}$			2. Mihalose	2. Dellenose	2. Vulsinose	2			
Subrang 3, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$		2. x	3. Tehamose	3. Toscanose	3. Pulaskose	3. x			
Subrang 4, Dosodic, $\frac{K_2O}{Na_2O} < \frac{3}{5} > \frac{1}{7}$		3. x	4. Alsbachose	4. Lassenose	4. Laurvikose	4. Viezzenose			
Subrang 5, Persodic, $\frac{K_2O}{Na_2O} < \frac{1}{7}$			5. Yukonose	5. Mariposose	5. x	5			
RANG 3, ALKALICALCIC, $\frac{K_2O + Na_2O}{CaO} < \frac{5}{3} > \frac{3}{5}$		3. x	3. *Riesenase*	3. *Coloradase*	3. x	3			
Subrang 1, Perpotassic, $\frac{K_2O}{Na_2O} > \frac{7}{1}$		1	1	1	1				
Subrang 2, Dopotassic, $\frac{K_2O}{Na_2O} < \frac{7}{1} > \frac{5}{3}$			2. x	2. x	2. x				
Subrang 3, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$		2. x	3. Riesenose	3. Amiatose	3. x				
Subrang 4, Dosodic, $\frac{K_2O}{Na_2O} < \frac{3}{5} > \frac{1}{7}$		3. x	4. x	4. Yellowstonose	4. x				
Subrang 5, Persodic, $\frac{K_2O}{Na_2O} < \frac{1}{7}$			5. Vulcanose	5. Amadorose	5. x				
RANG 4, DOCALCIC, $\frac{K_2O + Na_2O}{CaO} < \frac{3}{5} > \frac{1}{7}$			4. x	4. x	4. *Labradorase*	4. x			
Subrang 1, Prepotassic, $\frac{K_2O}{Na_2O} > \frac{5}{3}$			1. x	1	1	1			
Subrang 2, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$			2. x	2	2	2			
Subrang 3, Presodic, $\frac{K_2O}{Na_2O} < \frac{3}{5}$			3	3. x	3. Labradorose	3. x			
RANG 5, PERCALCIC, $\frac{K_2O + Na_2O}{CaO} < \frac{1}{7}$					5. *Canadase*				

NOTE.—X indicates that analyses are known which belong to this division, but that no name is suggested by us.

	8, $\frac{L}{F} < \frac{7}{1} > \frac{5}{3}$ CAMPANARE.	9, $\frac{L}{F} > \frac{7}{1}$ LAPPARE.
RANG 1, PERALKALIC,	1. x	1. *Urtase*
Subrang 1, Perp	1.	1 . . . .
Subrang 2, Dopo	2.	2 . . . .
Subrang 3, Sodip	3. x	3. Arkansose
Subrang 4, Doso	4.	4. x
Subrang 5, Perso	5. x	5. Urtose
RANG 2, DOMALKALIC	2. *Vesuvase*	. . . .
Subrang 1, Perpo	1.	. . . .
Subrang 2, Dopo	2. Vesuvose	. . . .
Subrang 3, Sodip	3.	. . . .
Subrang 4, Doso	4. x	. . . .
Subrang 5, Perso	5.	. . . .
RANG 3, ALKALICALC	. . . .	. . . .
Subrang 1, Perp	. . . .	. . . .
Subrang 2, Dopo	. . . .	. . . .
Subrang 3, Sodi	. . . .	. . . .
Subrang 4, Dosc	. . . .	. . . .
Subrang 5, Pers	. . . .	. . . .
RANG 4, DOCALCIC,	. . . .	. . . .
Subrang 1, Prep	. . . .	. . . .
Subrang 2, Sodip	. . . .	. . . .
Subrang 3, Preso	. . . .	. . . .
RANG 5, PERCALCIC,	. . . .	. . . .

NOTE.—X indicates th

CLASS II, DOSALANE, $\frac{SAL}{FEM} < \frac{7}{1} > \frac{5}{3}$. SUBCLASS I, DOSALONE, $\frac{QFL}{CZ} > \frac{7}{1}$.

ORDER	1, $\frac{Q}{F} > \frac{7}{1}$	2, $\frac{Q}{F} < \frac{7}{1} > \frac{5}{3}$	3, $\frac{Q}{F} < \frac{5}{3} > \frac{3}{5}$ HISPANARE.	4, $\frac{Q}{F} < \frac{3}{5} > \frac{1}{7}$ AUSTRARE.	5, $\frac{Q,L}{F} < \frac{7}{1}$ GERMANARE.	6, $\frac{L}{F} < \frac{3}{5} > \frac{1}{7}$ NORGARE.	7, $\frac{L}{F} < \frac{3}{5} > \frac{5}{3}$ ITALARE.	8, $\frac{L}{F} < \frac{7}{1} > \frac{5}{3}$ CAMPANARE.	9, $\frac{L}{F} > \frac{7}{1}$ LAPPARE.
RANG 1, PERALKALIC, $\frac{K_2O+Na_2O}{CaO} < \frac{7}{1}$			1. *Varingase*	1. *Pantellerase*	1. *Umptekase*	1. *Laurdalase*	1. *Lujavrase*	1. x	1. *Urtase*
Subrang 1, Perpotassic, $\frac{K_2O}{Na_2O} > \frac{7}{1}$			1.	1.	1.	1.	1.	1.	1.
Subrang 2, Dopotassic, $\frac{K_2O}{Na_2O} < \frac{7}{1} > \frac{5}{3}$			2.	2.	2 Highwoodose.	2. Fergusose	2.	2.	2.
Subrang 3, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$			3. Varingose	3. Grorudose	3. Ilmenose	3. Judithose	3. Janeirose	3. x	3. Arkansose
Subrang 4, Dosodic, $\frac{K_2O}{Na_2O} < \frac{3}{5} > \frac{1}{7}$			4. x	4. Pantellerose	4. Umptekose	4. Laurdalose	4. Lujavrose	4.	4. x
Subrang 5, Persodic, $\frac{K_2O}{Na_2O} < \frac{1}{7}$			5.	5.	5.	5.	5.	5. x	5. Urtose
RANG 2, DOMALKALIC, $\frac{K_2O+Na_2O}{CaO} < \frac{7}{1} > \frac{5}{3}$			2. x	2. *Dacase*	2. *Monzonase*	2. *Essexase*	2. *Vulturase*	2. *Vesuvase*	
Subrang 1, Perpotassic, $\frac{K_2O}{Na_2O} > \frac{7}{1}$			1.	1.	1.	1.	1.	1.	
Subrang 2, Dopotassic, $\frac{K_2O}{Na_2O} < \frac{7}{1} > \frac{5}{3}$			2. x	2.	2. Ciminose	2. x	2. x	2. Vesuvose	
Subrang 3, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$			3. x	3. Adamellose	3. Monzonose	3. Borolanose	3. x	3.	
Subrang 4, Dosodic, $\frac{K_2O}{Na_2O} < \frac{3}{5} > \frac{1}{7}$			4.	4. Dacose	4. Akerose	4. Essexose	4. Vulturose	4. x	
Subrang 5, Persodic, $\frac{K_2O}{Na_2O} < \frac{1}{7}$			5.	5.	5. x	5.	5.	5.	
RANG 3, ALKALICALCIC, $\frac{K_2O+Na_2O}{CaO} < \frac{5}{3} > \frac{3}{5}$			3. *Almerase*	3. *Tonalase*	3. *Andase*	3. *Salemase*	3. x		
Subrang 1, Perpotassic, $\frac{K_2O}{Na_2O} > \frac{7}{1}$			1.	1.	1.	1. x	1.		
Subrang 2, Dopotassic, $\frac{K_2O}{Na_2O} < \frac{7}{1} > \frac{5}{3}$			2.	2. x	2. x	2. x	2.		
Subrang 3, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$			3. Almerose	3. Harzose	3. Shoshonose	3. x	3. x		
Subrang 4, Dosodic, $\frac{K_2O}{Na_2O} < \frac{3}{5} > \frac{1}{7}$			4. Sitkose	4. Tonalose	4. Andose	4. Salemose	4. x		
Subrang 5, Persodic, $\frac{K_2O}{Na_2O} < \frac{1}{7}$			5.	5. Placerose	5. Beerbachose	5. x	5.		
RANG 4, DOCALCIC, $\frac{K_2O+Na_2O}{CaO} < \frac{3}{5} > \frac{1}{7}$			4. x	4. *Bandase*	4. *Hessase*	4. x			
Subrang 1, Prepotassic, $\frac{K_2O}{Na_2O} > \frac{5}{3}$			1. x	1. Sagamose	1.	1.			
Subrang 2, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$			2.	2. x	2. x	2.			
Subrang 3, Presodic, $\frac{K_2O}{Na_2O} < \frac{3}{5}$			3. x	3. Bandose	3. Hessose	3. x			
RANG 5, PERCALCIC, $\frac{K_2O+Na_2O}{CaO} < \frac{1}{7}$			5. *Gordonase*		5. *Corsase*				

NOTE.—X indicates that analyses are known which belong to this division, but that no name is suggested by us.

	8, $\frac{L}{F} < \frac{7}{1} > \frac{5}{3}$ BOHEMARE.	9, $\frac{L}{F} > \frac{7}{1}$ FINNARE.
RANG 1, PERALKA	1. *Chotase*	1. *Ijolase*
Subrang 1,	1.	1. . . . .
Subrang 2,	2. Chotose	2. Madupose
Subrang 3,	3.	3. . . . .
Subrang 4,	4.	4. Iiwarose
Subrang 5,	5.	5. Ijolose
RANG 2, DOMALK	2. *Albanase*	. . . .
Subrang 1,	1.	. . . .
Subrang 2,	2. Albanose	. . . .
Subrang 3,	3. x	. . . .
Subrang 4,	4. Covose	. . . .
Subrang 5,	5. x	. . . .
RANG 3, ALKAL	. . . .	. . . .
Subrang 1,	. . . .	. . . .
Subrang 2,	. . . .	. . . .
Subrang 3,	. . . .	. . . .
Subrang 4,	. . . .	. . . .
Subrang 5,	. . . .	. . . .
RANG 4, DOCALC	. . . .	. . . .
Subrang 1,	. . . .	. . . .
Subrang 2,	. . . .	. . . .
Subrang 3,	. . . .	. . . .
RANG 5, PERCALC	. . . .	. . . .

NOTE.—X indica

CLASS III, SALFEMANE, $\frac{SAL}{FEM} < \frac{5}{3} > \frac{3}{5}$. SUBCLASS I, SALFEMONE, $\frac{QFL}{CZ} > \frac{7}{1}$.

ORDER	1, $\frac{Q}{F} > \frac{7}{1}$	2, $\frac{Q}{F} < \frac{7}{1} > \frac{5}{3}$	3, $\frac{Q}{F} < \frac{5}{3} > \frac{3}{5}$ ATLANTARE.	4, $\frac{Q}{F} < \frac{3}{5} > \frac{1}{7}$ VAALARE.	5, $\frac{Q,L}{F} < \frac{1}{7}$ GALLARE.	6, $\frac{L}{F} < \frac{3}{5} > \frac{1}{7}$ PORTUGARE.	7, $\frac{L}{F} < \frac{5}{3} > \frac{3}{5}$ KAMERUNARE.	8, $\frac{L}{F} < \frac{7}{1} > \frac{5}{3}$ BOHEMARE.	9, $\frac{L}{F} > \frac{7}{1}$ FINNARE.
RANG 1, PERALKALIC, $\frac{K_2O+Na_2O}{CaO} > \frac{7}{1}$			1. *Rockallase*	1	1. *Orendase*	1. *Wyomingase*	1. *Malignase*	1. *Chotase*	1. *Ijolase*
Subrang 1, Perpotassic, $\frac{K_2O}{Na_2O} > \frac{7}{1}$			1		1. Orendose	1. Wyomingose	1	1	1
Subrang 2, Dopotassic, $\frac{K_2O}{Na_2O} < \frac{7}{1} > \frac{5}{3}$			2		2	2	2	2. Chotose	2. Madupose
Subrang 3, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$			3. x		3	3. x	3	3	3
Subrang 4, Dosodic, $\frac{K_2O}{Na_2O} < \frac{3}{5} > \frac{1}{7}$			4		4	4. x	4. Malignose	4	4. Iiwarose
Subrang 5, Persodic, $\frac{K_2O}{Na_2O} < \frac{1}{7}$			5. Rockallose		5	5	5	5	5. Ijolose
RANG 2, DOMALKALIC, $\frac{K_2O+Na_2O}{CaO} < \frac{7}{1} > \frac{5}{3}$				2	2. *Kilauase*	2. *Monchiquase*	2. *Kamerunase*	2. *Albanase*	
Subrang 1, Perpotassic, $\frac{K_2O}{Na_2O} < \frac{7}{1}$					1	1	1	1	
Subrang 2, Dopotassic, $\frac{K_2O}{Na_2O} < \frac{7}{1} > \frac{5}{3}$					2. Prowersose	2	2	2. Albanose	
Subrang 3, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$					3. Lamarose	3. Shonkinose	3. x	3. x	
Subrang 4, Dosodic, $\frac{K_2O}{Na_2O} < \frac{3}{5} > \frac{1}{7}$					4. Kilauose	4. Monchiquose	4. Kamerunose	4. Covose	
Subrang 5, Persodic, $\frac{K_2O}{Na_2O} < \frac{1}{7}$					5. x	5	5. x	5. x	
RANG 3, ALKALICALCIC, $\frac{K_2O+Na_2O}{CaO} < \frac{5}{3} > \frac{3}{5}$				3. *Vaalase*	3. *Camptonase*	3. *Limburgase*	3. *Etindase*		
Subrang 1, Perpotassic, $\frac{K_2O}{Na_2O} > \frac{7}{1}$				1	1	1	1		
Subrang 2, Dopotassic, $\frac{K_2O}{Na_2O} < \frac{7}{1} > \frac{5}{3}$				2	2. Absarokose	2	2. x		
Subrang 3, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$				3	3. Kentallenose	3. Ourose	3		
Subrang 4, Dosodic, $\frac{K_2O}{Na_2O} < \frac{3}{5} > \frac{1}{7}$				4. Vaalose	4. Camptonose	4. Limburgose	4. Etindose		
Subrang 5, Persodic, $\frac{K_2O}{Na_2O} < \frac{1}{7}$				5	5. Ornose	5. x	5. x		
RANG 4, DOCALCIC, $\frac{K_2O+Na_2O}{CaO} < \frac{3}{5} > \frac{1}{7}$				4. x	4. *Auvergnase*	4. x	4. x		
Subrang 1, Prepotassic, $\frac{K_2O}{Na_2O} > \frac{5}{3}$				1	1	1	1		
Subrang 2, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$				2	2. x	2. x	2. x		
Subrang 3, Presodic, $\frac{K_2O}{Na_2O} < \frac{3}{5}$				3. x	3. Auvergnose	3. x	3		
RANG 5, PERCALCIC, $\frac{K_2O+Na_2O}{CaO} < \frac{1}{7}$					5. *Kedabekase*				

NOTE.—X indicates that analyses are known which belong to this division, but that no name is suggested by us.

E, $\frac{\text{SAL}}{\text{FEM}}$

$\frac{5}{3}$, SCO ACKARE.				ORDER 5
$\frac{5}{3}>\frac{3}{5}$ …re.	$\frac{3}{5}$ …e.	4. $\frac{H}{T}<\frac{3}{5}>\frac{1}{7}$ x	5, $\frac{H}{T}<\frac{1}{7}$	
RA …*se*	…*ase*	1............	....	No analyses known.
S…uettiase	…iase	1............	....	
....	....	1............	....	
…uettose	....	2............	....	
....	....	3............	....	
....		4............	....	
....	....	5............	....	
S…diase	....	....	....	
	....	....	....	
…lose	....	....	....	
....	....	....	....	
Se…….	....	....	....	
....	....	....	....	
....	....	....	....	
....	....	....	....	

CLASS IV, DOFEMANE, $\frac{SAL}{FEM} < \frac{3}{5} > \frac{1}{7}$. SUBCLASS I, DOFEMONE, $\frac{POM}{A} > \frac{7}{1}$.

SECTION	ORDER 1, $\frac{P, O}{M} > \frac{7}{1}$, HUNGARARE. 1, $\frac{P}{O} > \frac{7}{1}$ Minnesotiare.	2, $\frac{P}{O} < \frac{7}{1} > \frac{5}{3}$ x	3, $\frac{P}{O} < \frac{5}{3} > \frac{3}{5}$ Hungariare.	4, $\frac{P}{O} < \frac{3}{5} > \frac{1}{7}$ x	5, $\frac{P}{O} < \frac{1}{7}$ Pyreniare.
RANG I, PERMIRLIC, $\frac{CaO + MgO + FeO}{Na_2O} > \frac{7}{1}$	1. *Minnesotase*	1. x	1. *Wehrlase*	1. *Cortlandtase*	1. *Lherzase*
Section 1, Permiric, $\frac{MgO + FeO}{CaO} > \frac{7}{1}$	1. Minnesotiase	1.	1. Wehrliase	1. Cortlandtiase	1. Lherziase
Subrang 1, Permagnesic, $\frac{MgO}{FeO} > \frac{7}{1}$	1.	1.	1. x	1. Cortlandtose	1. Lherzose
Subrang 2, Domagnesic, $\frac{MgO}{FeO} < \frac{7}{1} > \frac{5}{3}$	2. Cookose	2.	2. Wehrlose	2. Custerose	2. Argeinose
Subrang 3, Magnesiferrous, $\frac{MgO}{FeO} < \frac{5}{3} > \frac{3}{5}$	3.	3.	3.	3.	3.
Subrang 4, Doferrous, $\frac{MgO}{FeO} < \frac{3}{5} > \frac{1}{7}$	4.	4.	4.	4.	4.
Subrang 5, Perferrous, $\frac{MgO}{FeO} < \frac{1}{7}$	5.	5.	5.	5.	5.
Section 2, Domiric, $\frac{MgO + FeO}{CaO} < \frac{7}{1} > \frac{5}{3}$		2. x	2. x	2. x	2.
Subrang 1, Permagnesic, $\frac{MgO}{FeO} > \frac{7}{1}$		1. Belcherose	1. x	1.	1.
Subrang 2, Domagnesic, $\frac{MgO}{FeO} < \frac{7}{1} > \frac{5}{3}$		2. x	2. Rossweinose	2.	
Subrang 3, Magnesiferrous, $\frac{MgO}{FeO} < \frac{5}{3} > \frac{3}{5}$ Subrangs 4 and 5 not represented.		3.	3.	3. x	
Section 3, Calcimiric, $\frac{MgO + FeO}{CaO} < \frac{5}{3} > \frac{3}{5}$					3. Venanziase
Subrang 1, Permagnesic, $\frac{MgO}{FeO} > \frac{7}{1}$					1.
Subrang 2, Domagnesic, $\frac{MgO}{FeO} < \frac{7}{1} > \frac{5}{3}$					2. Venanzose
Subrang 3, Magnesiferrous, $\frac{MgO}{FeO} < \frac{5}{3} > \frac{3}{5}$ Subrangs 4 and 5 not represented.					3.

SECTION	ORDER 2, $\frac{P, O}{M} < \frac{7}{1} > \frac{5}{3}$, SCOTARE. 1, $\frac{P}{O} > \frac{7}{1}$ x	2, $\frac{P}{O} < \frac{7}{1} > \frac{5}{3}$ Paoliare.	3, $\frac{P}{O} < \frac{5}{3} > \frac{3}{5}$ Texiare.	4, $\frac{P}{O} < \frac{3}{5} > \frac{1}{7}$ x	5, $\frac{P}{O} < \frac{1}{7}$ x
RANG I, PERMIRLIC	1. x	1. *Paolase*	1. *Texase*	1. *Casselase*	1. x
Section 1, Permiric	1.	1 Valbonniase	1. Marquettiase	1. x	1. Kalteniase
Subrang 1, Permagnesic		1. Valbonnose	1.	1. x	1.
Subrang 2, Domagnesic			2. Marquettose	2. x	2.
Subrang 3, Magnesiferrous			3	3.	3. Kaltenose
Subrang 4, Doferrous			4.	4.	4.
Subrang 5, Perferrous			5.	5.	5.
Section 2, Domiric	2.	2. x	2. Uvaldiase	2. Casseliase	2. x
Subrang 1, Permagnesic	1.	1.	1. x	1. x	1.
Subrang 2, Domagnesic	2.	2. x	2. Uvaldose	2. Casselose	2. x
Subrang 3, Magnesiferrous	3.	3.	3.	3.	3.
Section 3, Calcimiric	3. Brandbergiase	3. Paoliase			
Subrang 1, Permagnesic	1.	1.			
Subrang 2, Domagnesic	2. Brandbergose	2. Paolose			
Subrang 3, Magnesiferrous	3.	3.			

SECTION	ORDER 3, $\frac{P, O}{M} < \frac{5}{3} > \frac{3}{5}$, SVERIGARE. 1, $\frac{P}{O} > \frac{7}{1}$ Bergeniare.	2, $\frac{P}{O} < \frac{7}{1} > \frac{5}{3}$ x	3, $\frac{P}{O} < \frac{5}{3} > \frac{3}{5}$	4, $\frac{P}{O} < \frac{3}{5} > \frac{1}{7}$ x	5, $\frac{P}{O} < \frac{1}{7}$ Sverigiare.
RANG I, PERMIRLIC	1. *Bergenase*	1. x	1.	1. x	1. *Tabergase*
Section 1, Permiric	1. Bergeniase	1.	1.	1.	1. Tabergiase
Subrang 1, Permagnesic	1.				1.
Subrang 2, Domagnesic	2.				2.
Subrang 3, Magnesiferrous	3. Bergenose				3.
Subrang 4, Doferrous	4.				4.
Subrang 5, Perferrous	5.				5.
Section 2, Domiric	2.	2. x	2.	2. x	
Subrang 1, Permagnesic		1.		1.	
Subrang 2, Domagnesic		2. x		2. x	
Subrang 3, Magnesiferrous		3.		3.	
Section 3, Calcimiric		3. Avezaciase			
Subrang 1, Permagnesic		1.			
Subrang 2, Domagnesic		2.			
Subrang 3, Magnesiferrous		3. Avezacose			

SECTION	ORDER 4, $\frac{P, O}{M} < \frac{3}{5} > \frac{1}{7}$, ADIRONDACKARE. Suborder	1, $\frac{H}{T} > \frac{7}{1}$	2, $\frac{H}{T} < \frac{7}{1} > \frac{5}{3}$ Adirondackore.	3, $\frac{H}{T} < \frac{5}{3} > \frac{3}{5}$ Champlainore.	4, $\frac{H}{T} < \frac{3}{5} > \frac{1}{7}$ x	5, $\frac{H}{T} < \frac{1}{7}$
RANG I, PERMIRLIC			1. *Adirondackase*	1. *Champlainase*	1.	
Section 1, Permiric			1. Adirondackiase	1. Champlainiase	1.	
Subrang 1, Permagnesic			1.	1.	1.	
Subrang 2, Domagnesic			2.	2.	2.	
Subrang 3, Magnesiferrous			3.	3.	3.	
Subrang 4, Doferrous			4. x	4. x	4.	
Subrang 5, Perferrous			5.	5.	5.	
Section 2, Domiric						
Subrang 1, Permagnesic						
Subrang 2, Domagnesic						
Subrang 3, Magnesiferrous						
Section 3, Calcimiric						
Subrang 1, Permagnesic						
Subrang 2, Domagnesic						
Subrang 3, Magnesiferrous						

ORDER 5

No analyses known.

tion and the actual, there is obviously no need of mentioning details of the actual mineral composition, since this is fully

CLASS V, PER

SECTION

Rang 1, Permirlic, $\frac{CaO + MgO + FeO}{Na_2O}$

Section 1, Permiric, $\frac{MgO + FeO}{CaO} > \frac{7}{1}$ . .

Subrang 1, Permagnesic, $\frac{MgO}{FeO} > \frac{7}{1}$ . .

Subrang 2, Domagnesic, $\frac{MgO}{FeO} < \frac{7}{1} >$

Subrang 3, Magnesiferrous, $\frac{MgO}{FeO} <$

Subrang 4, Doferrous, $\frac{MgO}{FeO} < \frac{3}{5} > \frac{1}{7}$.

Subrang 5, Perferrous, $\frac{MgO}{FeO} < \frac{1}{7}$ . . . .

Section 2, Domiric, $\frac{MgO + FeO}{CaO} < \frac{7}{1} > \frac{5}{3}$

Subrang 1, Permagnesic, $\frac{MgO}{FeO} > \frac{7}{1}$ . .

Subrang 2, Domagnesic, $< \frac{7}{1} > \frac{5}{3}$ . . .

Subrangs 3, 4, and 5 not represented

CLASS V, PERFEMANE, $\frac{SAL}{FEM} < \frac{1}{7}$. SUB-CLASS I, PERFEMONE, $\frac{POM}{A} > \frac{7}{1}$.

SECTION	ORDER 1. $\frac{P, O}{R} > \frac{7}{1}$, MAORARE.				
	1, $\frac{P}{O} > \frac{7}{1}$ CAROLINIARE.	2, $\frac{P}{O} < \frac{7}{1} > \frac{5}{3}$ MARYLANDIARE	3, $\frac{P}{O} < \frac{5}{3} > \frac{3}{5}$	4, $\frac{P}{O} < \frac{3}{5} > \frac{1}{7}$ X	5, $\frac{P}{O} < \frac{1}{7}$ MAORIARE.
RANG 1, PERMIRLIC, $\frac{CaO + MgO + FeO}{Na_2O} > \frac{7}{1}$	1. *Websterase*	1. *Baltimorase*	1	1. x	1. *Dunase*
Section 1, Permiric, $\frac{MgO + FeO}{CaO} > \frac{7}{1}$	1. Mariciase	1. x	1	1. x	1. Duniase
Subrang 1, Permagnesic, $\frac{MgO}{FeO} > \frac{7}{1}$	1. Maricose	1. x	1	1. x	1. Dunose
Subrang 2, Domagnesic, $\frac{MgO}{FeO} < \frac{7}{1} > \frac{5}{3}$	2	2	2	2. x	2 ....
Subrang 3, Magnesiferrous, $\frac{MgO}{FeO} < \frac{5}{3} > \frac{3}{5}$	3	3	3	3	3 ....
Subrang 4, Doferrous, $\frac{MgO}{FeO} < \frac{3}{5} > \frac{1}{7}$	4	4	4	4	4 ....
Subrang 5, Perferrous, $\frac{MgO}{FeO} < \frac{1}{7}$	5	5	5	5	5 ....
Section 2, Domiric, $\frac{MgO + FeO}{CaO} < \frac{7}{1} > \frac{5}{3}$	2. Websteriase	2. Baltimoriase	....	....	....
Subrang 1, Permagnesic, $\frac{MgO}{FeO} > \frac{7}{1}$	1. Websterose	1. x	....	....	....
Subrang 2, Domagnesic, $< \frac{7}{1} > \frac{5}{3}$	2. Cecilose	2. Baltimorose	....	....	....
Subrangs 3, 4, and 5 not represented	3	3	....	....	....

~~Other orders of Class V not represented by analyses.~~

tion and the actual, there is obviously no need of mentioning details of the actual mineral composition, since this is fully expressed by the norm. To indicate this mode it is only necessary to use the word *normative*, before the magmatic name and connected with a hyphen.

As has been already remarked, though all the various possible combinations of the feldspar molecules are regarded as standard, yet it will often be found needful to indicate the special feldspars actually crystallized. In this case, since the albite most often crystallizes with the anorthite molecule, forming a soda-lime plagioclase, and since the character of this will condition that of the alkali-feldspar, it will in general only be necessary to name the soda-lime plagioclase which is present. If, however, it is desirable to indicate the presence of microline or anorthoclase, this can also be done.

To express the extent to which the mode of a rock differs from the norm it is necessary to state the kinds of minerals which are different as well as the amount to which they have been developed.

It is proposed to use the names of the minerals in question as adjective qualifiers of the magmatic name, as has been the custom with such names as mica-diorite, and to express their quantitative relations by means of prefixes or suffixes, or by the order of their arrangement when several mineral names are employed.

Owing to the interdependence of the minerals in any rock on each other and on the chemical composition of the magma, it is evident that, given the norm of a rock, which is involved in its magma name, it is only necessary to state the presence and amount of certain minerals developed, which are not in accord with the norm, in order to determine the modifications of the standard minerals consequent upon the development of these particular ones.

And since such modifications take place in all degrees, from the slightest possible change to the greatest possible, it is necessary to recognize in a systematic manner differences of degree.

Those already suggested in the chapter on classification with respect to actual mineral classification are two: (1) modifications of the norm, which are so slight as not to interfere with the classification of the rock directly from the mode; and (2) modifications of the norm so considerable that the rock cannot be classified directly from the mode without readjustment of the molecules in accordance with the method of calculation for obtaining the norm.

In other words, we may distinguish (1) variations among the actual minerals which fall within the limits possible in rocks with normative modes, and (2) those variations among the minerals which cause the rock to possess an abnormative mode.

1. Minerals of the first kind may be termed *varietal* minerals. They may be defined as minerals whose presence serves to characterize and distinguish different rocks of one magma unit, but whose amount is so small that they do not affect the character of the mode as normative or abnormative. Varietal minerals include: standard minerals whose presence is not indicated by the general expression of the norm, that is, the magmatic name, though an exact statement of the norm would recognize their presence; or they may include any of the non-standard minerals. For example: small amounts of quartz or feldspathoid in rocks of Order 5, in Classes I, II, III; or small amounts of hornblende and biotite, etc.

It is proposed to express in the nomenclature the presence of varietal minerals in the rock by adding to the name of the mineral the suffix *-ic*. When it is necessary to use several varietal qualifiers at one time the mineral names are to be connected by hyphens and the suffix applied to the last, as hornblende-biotitic alsbachose.

2. Minerals of the second kind, whose presence and amounts are such as to produce abnormative modes are called *critical* minerals, as already mentioned. They are for the most part alferric, but may be salic or femic, according to the mode of the rock.

It is proposed to express the presence of a critical mineral

in a rock by using the name of the mineral without modification, compounding it with the magmatic name by means of a hyphen.

In case there are several critical minerals present, their names are to be used in such order that the most abundant stands nearest to the magmatic name, and the least abundant the farthest from it.

It may become desirable when the number of mineral names is considerable to abbreviate and compound them in the manner suggested by Chamberlin,[1] and Jevons.[2]

It is to be remarked that it will not always be necessary to state the exact character or species of the critical mineral. It will often merely be necessary to mention the mineral group, whether augite, hornblende, mica, garnet, etc. This is because experience shows that in a magma of a given character the augite or hornblende formed will in general be of a more or less constant character. Thus in highly calcic magmas the augite will in general be of one kind, in sodic magmas of another, and in magnesic magmas of another.

The critical minerals, especially the alferric, may be developed within wide limits, which in the more femic Classes may be illustrated by three rocks of the dosodic Subrang of the alkalicalcic Rang of the Order portugare, of the salfemane Class. In this we find the hornblendite of Gran, which consists entirely of an alkalic hornblende, with no visible salic or femic minerals. Here also belongs the olivine-gabbro-diabase of the same locality, in which much of the feldspar has actually crystallized as such, and in which the hornblende consequently is less alkalic, and augite is present. We also find here a nephelite-basanite of Colfax county, New Mexico, in which the actual composition corresponds quite closely with the norm. The chemical analyses of these three rocks show their chemical likeness.

In the first case all the possible alferric mineral has been formed, as hornblende, in the second case only a part, approxi-

[1] *Geology of Wisconsin*, Vol. I. pp. 30–40. Madison, 1883.

[2] *Geol. Mag.*, Vol. VIII, p. 304, 1901.

No.	1.	2.	3.	No.	1.	2.	3.
SiO_2	37.90	43.65	42.35	P_2O_5	tr	tr	.99
Al_2O_3	13.17	11.48	12.29	SO_3	.....	.....	.05
Fe_2O_3	8.83	6.32	3.89	S	.....	.....	tr
FeO	8.37	8.00	7.05	Cr_2O_3	.....	.....	.10
MgO	9.50	7.92	13.09	V_2O_3	.....	.....	.04
CaO	10.75	14.00	12.49	NiO	.....	.....	.03
Na_2O	2.35	2.28	2.74	MnO	.....	.....	.21
K_2O	2.12	1.51	1.04	BaO	.....	.....	.10
H_2O+	1.40	1.00	1.50	SrO	.....	.....	.09
H_2O-	.....		.32	Li_2O	.....	.....	tr
CO_2	.....	tr	.....				
TiO_2	5.30	4.00	1.82		99.69	100.16	100.19

No. 1. Hornblendite, Brandberget, Gran, Norway. V. Schmelck, anal.; Brögger, *Erupt. Gest. Kryst. Geb.*, Vol. III (1899), p. 93.

No. 2. Olivine-gabbro-diabase, Brandberget, Gran, Norway. V. Schmelck, anal.; Brögger, *Quart. Jour. Geol. Soc.*, Vol. L (1894), p. 19.

No. 3. Nephelite-basanite, Ciruella, Colfax Co., N. M. W. F. Hillebrand, anal.; *Bull. 168, U. S. G. S.* (1900), p. 171.

mately half, chiefly as augite, while in the last very little such modification of the norm has taken place.

It is possible to devise a method of expressing in the nomenclature relative amounts of critical minerals for a comparatively simple case such as the one just given. But the problem is more complicated when several of these minerals, as hornblende, augite, and mica, are present at the same time, which frequently happens. The development of one modifies the maximum that may be attained by another, so that the expression of the relative degrees of development of each is a function of the others, and an exact expression in the nomenclature becomes extremely difficult, and is perhaps impracticable.

It will often be found useful to be able to indicate the presence of certain minerals in rock groups, when the relative amount which determines the Order, or lesser division, is not known or needful for the purpose in view. Thus we may want to speak of the persalanes or the dosalanes which carry quartz or nephelite, without specifying the relative amounts of these, *i. e.*, without making use of the ordinal divisions. In these

cases it is proposed that the name of the mineral be given followed by the word *-bearing*. So the cases just mentioned would be quartz-bearing or nephelite-bearing persalane and dosalane respectively. Such names indicate only that the rocks belong to these Classes and carry quartz or nephelite, with no implication of their other characters.

TEXTURE.

As already explained, the texture of a rock is to be expressed in the nomenclature by a qualifying term applied to the name of the magmatic unit, and connected with it by a hyphen.

There are now in use terms expressing some of the commonest and most characteristic textural features of igneous rocks. It is proposed to use these in their present form, or to modify them by abbreviation in some cases with the addition of syllables indicating the degree of granularity. The syllable *-o* is added to indicate that the texture is recognizable megascopically ; *-i* is added when it is microscopic. For example :

Granitic = xenomorphic and hypautomorphic granular ; *grano* = megascopically granitic, megagranitic ; *grani* = microscopically granitic, microgranitic.

Trachytic = panautomorphic with tabular feldspars ; *tracho* = megascopically trachytic, megatrachytic ; *trachi* = microscopically trachytic, microtrachytic.

Graphic = pegmatitic = granophyre in the Rosenbusch sense ; *grapho* = megagraphic ; *graphi* = micrographic.

Poikilitic ; poikilo = megapoikilitic ; *poikili* = micropoikilitic.

Ophitic ; ophito = megophitic ; *ophiti* = microphitic.

Felsitic = aphanitic ; *felso* = megafelsitic ; *felsi* = microfelsitic, microscopically homogeneous, but not isotropic glass.

Vitreous ; vitro = megascopically vitreous ; *vitri* = microscopically vitreous.

Spherulitic ; sphero = megaspherulitic ; *spheri* = microspherulitic.

Porphyritic ; phyro = megaporphyritic ; *phyri* = microporphyritic, that is, the phenocrysts are not megascopically notable, or are quite insignificant.

With the term *phyr* may be combined one indicating the texture of the groundmass as follows :

Porphyritic granitic ; granophyro = megagranitic, megaporphyritic ;

graniphyro = micrograinitic, megaporphyritic (granophyric in the Vogelsang sense); *graniphyri* = microgranitic, microporphyritic.

Porphyritic graphic; graphophyro = megagraphic, megaporphyritic; *graphiphyro* = micrographic, megaporphyritic; *graphiphyri* = micrographic, microporphyritic.

Porphyritic felsitic; felsophyro = megascopically felsitic and porphyritic; *felsophyri* = megafelsitic, microporphyritic; *felsiphyri* = microscopically felsitic and porphyritic.

Porphyritic vitreous; vitrophyro, vitrophyri, vitriphyro, vitriphyri.

Porphyritic poikilitic; poikilophyro, poikiliphyro, etc.

Porphyritic ophitic; ophitophyro, ophitiphyro, etc.

Aphyro = megascopically non-porphyritic, or *aphyric.*

Aphyri = microscopically non-porphyritic, or *aphyric.*

Salphyro = megascopically porphyritic with salic phenocrysts, *salphyric.*

Femphyro = megascopically porphyritic with femic phenocrysts, *femphyric.*

Alferphyro = megascopically porphyritic with alferric phenocrysts, *alferphyric.*

Salfemphyric, alfersalphyric, alferfemphyric etc.

From the foregoing statement we may summarize the method of formulating the nomenclature here proposed as follows:

1. The *magmatic name*, of whatever division is to be indicated, which is formed by the use of the locality root and appropriate termination, stands as the basis of nomenclature, and is the substantive part of the terminology. This is because the fundamental character of igneous rocks is the chemical composition of the magma, which persists whatever be the mineral development or the texture determined by conditions obtaining during solidification.

2. According to the information at hand, or to be conveyed, the *magmatic name* must be selected which represents the Class, Order, or other division to which the rock belongs. And this name may be qualified by mineral and textural adjectives. Thus it is possible to indicate the Class of a rock, when first observed in the field, and to describe its chararteristic mineral components, and its texture. If the relative proportions of its dominant minerals, salic or femic, can be readily determined, the magmatic name for the *Order* can be used. Subsequently more

specific magmatic names can be given to it. In each of these cases the critical mineral and the texture can be indicated by the same qualifying terms, or more precise ones if needed.

In this respect this system possesses a distinct advantage over former ones, in which no attempt has been made to indicate in the nomenclature the degree of exactness with which the rock is known or is to be described.

3. To indicate the actual mineral character of a rock when its *magmatic name* is given it is only necessary to express either the fact that it is standard or the departure from the norm by mentioning those *critical* minerals whose presence induces changes in the norm, or those *varietal* minerals which may be present. When such exactness is desired:

a) If the rock possesses a *normative mode* the actual mineral composition is expressed by using the word normative before the magmatic name.

b) If the rock does not possess a normative mode and it is desired to indicate the *critical* minerals present, it is proposed that such mineral qualifiers be used in some cases without introducing quantitative modifications. These mineral qualifiers may be used as full names attached to the magmatic name by a hyphen, as is the present practice, or they may be abbreviated and compounded.

c) It is suggested that the presence of small amounts of important minerals be indicated by adding the suffix *-ic* to the mineral name.

4. The texture is to be indicated by adjectives expressing the fabric, the crystallinity, and the granularity, and may be the terms in common use, those suggested above, or abbreviations of these.

5. Either mineral or textural qualifiers may be placed next to the magmatic name according to the emphasis to be given them, it being generally understood that the term nearest the magmatic name carries the strongest emphasis; the magmatic name coming last. The same rule is to be applied to the arrangement of several mineral qualifiers, that nearest the magmatic name is to be considered the most important.

Examples.—To illustrate the methods proposed, the following examples may be given, especial stress being laid on the possibility of expressing the exact amount of knowledge which is at hand or is to be conveyed.

1. The typical monzonite of Brögger, from Monzoni—an evenly granular, phaneric rock, composed, as seen in the field, of dominant feldspars, with only traces of quartz, considerable pyroxene, hornblende, and less biotite, with insignificant amounts of magnetite and apatite.

From the analysis by V. Schmelck[1] the following norm is calculated :

Orthoclase	26.1		
Albite	26.2		68.1
Anorthite	15.8		
Diopside	18.4		
Hypersthene	3.3	24.5	
Olivine	2.8		
Magnetite	5.3	6.1	31.9
Ilmenite	0.8		
Apatite	1.3	1.3	
			100.0

The rock belongs, therefore, to Class II, the *dosalanes*, with salic minerals dominant over femic, and this is evident even in the field.

Since, among the dominant salic minerals, neither quartz nor feldspathoids (lenads) are present, it belongs to the fifth Order, and is consequently, *germanare*. This, likewise, can be determined from the megascopic examination.

On referring to the analysis it is seen that the alkalies are to lime in normative anorthite as the ratio $0.097:0.057 = 1.70$. The rock, therefore, belongs to the second Rang, the domalkalic, to which we have given the name of *monzonase*. This, and the following points, could not be determined in the field.

As $K_2O' : Na_2O' :: 0.047 : 0.050$, the two are in nearly equal amount, and the Subrang is thus the third, sodipotassic, which we have called *monzonose*.

We have thus characterized the rock completely, as far as the dominant minerals are concerned. Taking up the subordi-

[1] W. C. Brögger, *Eruptivgest. Kristianiageb.* Vol. II, p. 24, 1895.

nate ones, we see from the norm that the pyroxenes and olivine are together dominant over the non-silicates, magnetite and ilmenite, the apatite being in negligible amount. The Grad is therefore the second, and this might be called *monzonate.*

Coming to Subgrad, we have to deal with the chemical character of the femic minerals. This is $(Mg, Fe)O:CaO'' :: 0.160:0.094 = 1.702$. The Subgrad is the second, domiric, and this might be named *monzonote.*

Taking up next the mode and texture, it has been seen that the mode is normative as far as the salic minerals are concerned, but that hornblende, with a little biotite, largely replaces the normative femic minerals. Hornblende is therefore the *critical* mineral and biotite the *varietal.* The texture is simply a normal granitic one and rather coarse, for which we use the term *grano.*

In the field, then, the rock would be referred to either its Class, as *biotitic hornblende-grano-dosalane*, or its Order, as *biotitic hornblende-germanare*, or as a *grano-hornblende-germanare*, if we wished to disregard the small amount of biotite and emphasize the hornblende content.

Further study with the microscope and in the laboratory would allow us to speak of the rock as *grano-hornblende-monzonase*, or *biotitic hornblende-grano-monzonose*, according to what information we wished to convey.

The augite-latite of the Dardanelle Flow, in Tuolumne county, California,[1] which belongs to the same Subrang, would be spoken of as *normative phyro-monzonose*, since the augite is almost wholly diopside. Since, however, in the norm of this rock pyroxene and magnetite are present in equal amounts, it would belong to the third Grad, which might be called *dardanellate.*

Similarly, confining ourselves to the same Subrang, the olivine-trachyte of the Arso, in Ischia, would be *olivinic-phyro-monzonose*, the gauteite of Hibsch[2], a *hornblende-trachiphyro-mon-*

[1]F. L. RANSOME, *A. J. S.*, Vol. V, p. 363, 1898.

[2]J. E. HIBSCH, *T. M. P. M.*, Vol. XVII, p. 84, 1897.

zonose, and the mica-basalt of Santa Maria Basin, Arizona,[1] a *felsophyro-biotite-monzonose*. A glassy facies of any of these, with hornblende phenocrysts, for example, would be *hornblende-vitro-monzonose*. A pure glass of this composition would be simply a *vitro-monzonose*, or *aphyrovitro-monzonose*; if microlitic it would be a *phyrivitro-monzonose*.

To take another example, the normal, lithoidal, micro-spherulitic and porphyritic rhyolite of the Yellowstone National Park is *spheriphyro-alaskose*, which is a very concise expression for a rock that is microscopically spherulitic, megascopically porphyritic, having the chemical composition of a rock whose norm consists of extreme salic minerals, of which quartz and feldspar are nearly equal, the feldspars extremely alkalic, and soda and potash in nearly equal proportions.

An example of intermediate rock is to be found in the granite of Butte, Mont., whose composition is discussed at length in connection with the calculation of norm and mode. This rock belongs near the border line between Classes I and II, and the rock from Walkerville Station, Butte, has $\frac{\text{sal}}{\text{fem}} = 7.14$. It is a persalane near dosalane, and may be called dosalane-persalane, which contracts to do-persalane.

The Order is quardofelic,

$$\frac{F}{Q} = 3.4, < \frac{7}{1} > \frac{5}{3};$$

it is britannare (Class I) near austrare (Class II), or austrare britannare. The Rang is alcalicalcic,

$$\frac{K_2O' + Na_2O'}{CaO'} = 1.38, < \frac{5}{3} > \frac{3}{5};$$

it is coloradase (Class I) near tonalase (Class II), or tonalase-coloradase. The Subrang is sodipotassic,

$$\frac{K_2O'}{Na_2O'} = 1, < \frac{5}{3} > \frac{3}{5};$$

it is amiatose (Class I) near harzose (Class II) or harzose-amiatose.

[1] *Bull*, *148 U. S. G. S.*, p. 187 (B, C, D), 1897.

TYPE AND HABIT.—It is clearly obvious that if great precision or completeness be desired, so that both mineralogical and textural qualifiers are used, the polynomial name resulting will be of considerable length, comparable to such present names as quartz-hornblende-biotite-diorite-porphyry. This will probably not be as great a practical difficulty or inconvenience as may appear at first sight, since after a given rock has been described and named in full in any given article, it may be referred to subsequently by its magmatic name alone, or by this in conjunction with a textural or modal term, according to circumstances.

However, since the same or similar assemblages of modal and textural characters are found in many localities it will be as well to be able to express these concisely. This is, after all, what is accomplished by many of the names in the present systems of nomenclature, although it has not been done systematically. Thus the names granite, rhyolite, tinguaite, laurvikite, etc., convey primarily an idea of the qualitative mineral composition and the texture of the respective rocks, with a very rough one of the magmatic character.

It is to be noted that there are two degrees of similarity among rocks which can be easily recognized and made use of. One is almost complete *identity*, the other a *general resemblance* which suggests identity.

Type.—For the first of these, *identity* or almost complete identity, we propose the use of the term *type*. Rocks of the same type are identical in norm, mode, and texture, or almost completely so. They are of the same grain, have the same fabric, the same actual mineral composition, and are so much alike that they may be mistaken for one another or might have been parts of one rock body. Many examples of such close similarity are familiar to all petrographers.

The particular modal and textural features which characterize rocks of a given type are to be expressed by a single adjective word, composed of a root derived from a geographical locality in which a rock of the type occurs, but not already employed to designate a magmatic unit, and the termination *-al*.

Habit.—In order to express the fact that one rock resembles in general appearance another well-known rock by exhibiting some of its characteristic features without being identical in composition or mode we propose to use the term *habit*, formerly in constant requisition among petrographers. The features of a rock characterizing its habit may be both textural and mineral. For example: one rock may be porphyritic, with a dark-colored, aphanitic groundmass, and the phenocrysts rhombic feldspars. Another rock may have these features, but belong to a chemically different magma. The two may be said to have the same habit. And the second may be sufficiently described by giving its proper magmatic name qualified by an adjective indicating the habit of the first rock.

To accomplish this we propose that the habit of a rock be expressed by a word formed similarly to one expressing type but with the termination *-oid*. The root of the word is to be taken from some geographical locality. It may be the same as one used for a type, since a common type rock may be one whose habit will often be used in describing another, less common, rock.

Thus a particular form of rock belonging to the Order russare, of the persalanes, may constitute the *tingual type*, with definite norm, mode, and texture; while a somewhat similarly appearing rock belonging to the Order norgare, of the dosalane Class may possess a *tinguoid habit*.

The habital qualifier may be applied to a magmatic name of any systematic division, since it does not specify the composition of a rock. Thus we may describe a rock as a tinguoid dosalane, or a tinguoid norgare, a tinguoid laurdalase, etc. There may be tinguoid persalanes and salfemanes.

It is obvious that, with the use of types and habits, the nomenclature will tend to become binomial, and hence much more easy of application than in the present systems, or in the full one proposed here. It will, however, differ radically from the binomial nomenclature in use in the organic sciences, since the habital qualifier will not correspond to the specific terms of

these, applicable only to the generic name, but will be applicable to any division of the classification from Class to Subgrad.

ROCK NAMES FOR GENERAL FIELD USE.

It is obvious that a considerable part of the system of classification and nomenclature here proposed can only be applied upon microscopical or chemical investigation. This is equally true of a large part of that in present use. There are many distinctions based on characters that cannot be observed with the unaided eye, such as differences among the plagioclase feldspars, and the mineral composition of aphanitic rocks.

It is also clear that the system demands a more detailed knowledge of rocks than many geologists, mining engineers, and others interested in geology, may care to acquire. This is a natural consequence of the advance in petrological science, which requires a corresponding advance in specialization and in petrographical classification and nomenclature.

For these reasons, which might be elaborated at considerable length, we are convinced of the need of general petrographical terms which will be serviceable in the field work of the petrologist, and which will be of use to the general geologist and to those who may not be able to carry on microscopical and chemical investigation.

Such general terms should be based on megascopic characters of the rocks and should be limited to such characters. Their application should be purely objective and everything of a subjective nature should be eliminated. It follows from this that such terms cannot be correlated with those used in the systematic nomenclature based on chemical and microscopical properties. They must be understood to have a totally different scope, and to indicate no more than the general megascopic characters with which they are connoted.

The attitude of the person using such terms is the same as that of geologists who studied rocks before the introduction of the microscope, and most of the distinctive features exhibited megascopically by igneous rocks were well known and appro-

priately named by the early geologists, and most of the terms used by them are in use at the present time, though their application has been variously modified by repeated redefinition.

We recommend that those terms which are needed for general field purposes, and are to be based on purely megascopic characters, be selected from the terms originally proposed by the founders of geology, and be given their original significance so far as possible, with only such modifications as a somewhat more systematic treatment of the matter may suggest.

When all igneous rocks are considered with reference to their megascopic characters their most generally recognizable features appear to be their *texture* and *color*, and in some cases, and to various degrees, their *mineral constituents*.

If we attempt to group them according to texture we find them falling into three large divisions:

1. Those whose mineral components can be seen with the unaided eye.

2. Those whose mineral components cannot all be seen with the unaided eye, and that are composed of a greater or less amount of lithoidal material not resolvable into its component parts.

3. Those with vitreous luster in the whole or a part of the mass.

The first have been called by Hauy phanerogène, and may be termed *phanerites*.

The second have been called by d'Aubuisson (1819) *aphanites*, a name which cannot be improved upon.

The third have been long known as volcanic glasses — *obsidian*, *pitchstone*, etc.

All phanerites, whether igneous or metamorphic, massive or schistose, were at an earlier time called *granite*. But at the beginning of the last century a number of kinds of phanerocrystalline (phaneric) rocks were recognized, the distinctions being based upon the minerals that could be identified megascopically. These minerals are: quartz, feldspar, leucite, nephelite, mica, hornblende, augite, the iron ores, etc. It

is to be remembered that there were no specific distinctions among the feldspars. It is equally true at this day that no specific distinctions can be made with the unaided eye among the lime-soda-feldspars, and that albite, oligoclase, andesine, and labradorite cannot be identified as such without optical or chemical tests. It follows from this that phaneric rocks cannot be classed by purely megascopical means as having alkali-feldspars, or more calcic feldspars. We must not attempt to subdivide these rocks on the basis of characters not recognizable megascopically and must content ourselves with employing mineral groups, such as feldspar, mica, amphibole (hornblende), pyroxene, etc., as bases for their field designation.

For these reasons we suggest the following use of familiar terms when rocks are to be named on a purely megascopical basis.

I. Phanerites—phanerocrystalline (phaneric) rocks.

1. *Granite*—all granular igneous rock composed of dominant quartz and feldspar, of any kind, with mica, hornblende, or other minerals in subordinate amount. This is the granite of Werner, von Leonhard, and other early geologists, and will include what is now termed granite, granodiorite, tonalite, and most quartz-diorites. It will embrace all light-colored, granular rocks with dominant feldspar and a noticeable amount of quartz. It will include the quartz- (hornblende) -syenites of earlier geologists.

2. *Syenite*—all granular igneous rocks composed of dominant feldspars, of any kind, with subordinate amounts of mica, hornblende, pyroxene, or other minerals, and without noticeable amount of quartz. This is the syenite of Werner, von Leonhard, and others, with slight modification, and will include modern syenite, anorthosite, and the more feldspathic monzonites, diorites, and gabbros. If it is desirable to distinguish the plagioclase rocks when recognizable, such as the coarse-grained anorthosites, they may be called plagioclase-syenites, or anorthosites.

3. *Diorite*—all granular igneous rocks with dominant hornblende and subordinate feldspar of any kind. This is the

diorite of d'Aubuisson (1819) as defined by von Leonhard (1823). It will include the less feldspathic diorites and hornblende-gabbros.

4. *Gabbro*—all granular igneous rocks with dominant pyroxene and subordinate feldspar of any kind, with or without hornblende and mica. Essentially the gabbro of von Leonhard. Since it is not possible to identify pyroxene as distinct from hornblende in many cases, megascopically, it will probably happen that all of those rocks which can be clearly seen to contain dominant hornblende will be called diorite, and all doubtful ones will be grouped with the distinctly pyroxenic gabbros. These rocks will include the less feldspathic gabbros and norites, and some diorites.

5. *Peridotite*, *pyroxenite*, and *hornblendite*—all granular igneous rocks composed almost completely of olivine, pyroxene, or hornblende, in variable proportions, with little or no feldspar. These names are to be applied as at present.

Other names in common use, which can be applied without confusion upon the basis of purely megascopical determination, may be used.

II. Aphanites—lithoidal, aphanitic rocks. These may be non-porphyritic or porphyritic, the aphanitic character being confined to the groundmass.

A. *Non-porphyritic forms*, having no recognizable mineral constituents, must be subdivided, if at all, upon the basis of color, luster, or other physical properties. The early distinctions were in reality on a basis of color, and were two:

1. *Felsite* (Gerhard, 1814), Phonolite (Klaproth, 1801), Petrosilex of the French geologists. *Felsite* includes all aphanitic igneous rocks that are non-porphyritic and are light-colored, in various tones, and with various lusters other than vitreous. They include lithoidite (von Richthoven, 1860), or lithoidal rhyolite, non-porphyritic trachite, and phonolite, and the lighter colored non-porphyritic andesites, latites, etc.

2. *Basalt*—all dark-colored, aphanitic, igneous rocks without phenocrysts. This will include the dark-colored andesites, non-

porphyritic basalts, diabases, and other lavas known by a number of names, which before the classic studies of Zirkel were grouped togther as basalt.

B. *Porphyry*—porphyritic forms may all be embraced within the general term of *porphyry*. They may be separated on a basis of color to correspond to the divisions above mentioned into two groups.

1. *Leucophyre* (Gümbel, 1874) and
2. *Melaphyre* (Brongniart, 1813).

Gümbel applied the term leucophyre to certain altered diabases of light color, which would not be included within the group here proposed, but the term was applied to altered rocks and has never been in general use, and may advantageously be redefined.

Leucophyres would include all porphyritic, aphanitic, igneous rocks, with light-colored groundmass, and with phenocrysts of any kind.

Melaphyres would include all porphyritic, aphanitic igneous rocks with dark-colored groundmass, and with phenocrysts of any kind.

According to the kinds of phenocrysts which may be identified megascopically these rocks may be named without reference to the color of the groundmass as:

Quartz-porphyry or *quartzophyre*.

Feldspar-porphyry or *feldsparphyre*, but not felsophyre, since this name is in common use for a porphyry with felsitic groundmass.

Hornblende-porphyry or *hornblendophyre*.

Mica-porphyry or *micaphyre*.

Augite porphyry or *augitophyre* (von Buch, 1824).

Olivine-porphyry or *olivinophyre* (Vogelsang, 1872).

If it is intended to indicate the color of the groundmass as light or dark, we may use the terms:

Quartz-leucophyre or *quartz-melaphyre*.

Feldspar-leucophyre or *feldspar-melaphyre*.

Hornblende-leucophyre or *hornblende-melaphyre*.

It is to be remembered that these terms leucophyre and melaphyre imply nothing as to the composition of the groundmass. They strictly indicate nothing but its color.

III. THE GLASSES—glassy rocks have been classified on a basis of luster and texture as follows:

1. *Obsidian*—vitreous rock of any color, usually black, often red, less often brown and greenish.

2. *Pitchstone*—resinous and less lustrous than obsidian, and consequently lighter colored.

3. *Perlite*—glassy rock with perlitic texture produced by small spheroidal fractures.

4. *Pumice*—highly vesicular glass, usually white or very light-colored.

Each of these varieties may be non-porphyritic or porphyritic. The latter may be called

Vitrophyre (Vogelsang, 1867) and may be qualified by mineral terms indicating the character of the prominent phenocrysts, yielding *quartz-vitrophyre*, *feldspar-vitrophyre*, etc. They may also be called porphyritic obsidian, pitchstone, perlite, or pumice.

PART III. METHODS OF CALCULATION.

In order to obtain concordant results in all cases in the determination of the kinds and amounts of standard minerals that correspond to a magma of any given chemical composition, a uniform method of calculation is necessary. This calculation may be made either from the chemical analysis of the rock or from the quantitative estimate of the minerals actually present in it.

The calculation of *standard minerals* belonging to the salic and femic groups, rather than that of the actual minerals which may be present in the rock, is warranted not only by the fact of the variable possibilities of crystallization in one magma, but because of the difficulty of determining the quantity and chemical character of the minerals actually present in many rocks. It is further warranted because of the impossibility of determining the minerals in a great number of rocks in which they are

too small, and because of the incomplete crystallization of all more or less glassy rocks.

The variability in the development and chemical composition of the *alferric minerals* justifies us in treating them as combinations by readjustment of salic and femic molecules. Their chemico-mineralogical relations and the method of calculating their proportions will be stated later on.

The method of calculation adopted is based upon a number of commonly observed chemico-mineralogical relations that obtain in the rock-making minerals, which may be stated as follows:

CHEMICAL RELATIONS AMONG SALIC MINERALS.—1. The constant relation between the molecules of Al_2O_3 and K_2O and Na_2O in orthoclase and albite, leucite and nephelite ($Al_2O_3 : K_2O + Na_2O :: 1 : 1$).

2. The somewhat similar relation between these constituents in the sodalites, where the soda is slightly in excess. The ratio in sodalite is $Al_2O_3 + \frac{1}{3}Cl_2 : Na_2O + \frac{1}{3}Na_2O :: 1 : 1$; in noselite it is $Al_2O_3 + \frac{1}{2}SO_3 : Na_2O + \frac{1}{2}Na_2O :: 1 : 1$.

3. The constant relation between Al_2O_3 and CaO in the anorthite molecule ($Al_2O_3 : CaO :: 1 : 1$).

4. The development of corundum under favorable conditions in rocks with excess of Al_2O_3 over K_2O, Na_2O, and CaO.

5. The relation between the development of alkali-feldspar (polysilicates) and of feldspathoids (meta- and ortho-silicates) and the available silica in the magma, so that free silica (quartz) does not crystallize together with leucite and nephelite.

6. The stronger affinity of Al_2O_3 for K_2O and Na_2O than for CaO, Al_2O_3 forming alkali-feldspars and feldspathoids (lenads) in preference to anorthite.

7. The constant ratio between ZrO_2 and SiO_2 in zircon, $ZrO_2 : SiO_2 :: 1 : 1$.

CHEMICAL RELATIONS AMONG FEMIC MINERALS.—1. The constant relation between Fe_2O_3 and Na_2O in the acmite molecule ($Fe_2O_3 : Na_2O :: 1 : 1$).

2. The general fact that this molecule is developed in magmas when K_2O and Na_2O are in excess of Al_2O_3.

3. The constant relation between Fe_2O_3 and FeO in magnetite (Fe_2O_3 : FeO : : 1 : 1).

4. The relation between FeO and TiO_2 in ilmenite (FeO : TiO_2 : : 1 : 1).

5. The relation of TiO_2 and CaO in titanite and in perofskite (TiO_2 : CaO : : 1 : 1).

6. The development of the titano-silicate, titanite, in the more siliceous rocks, and of the non-siliceous perofskite in its place in the less siliceous ones.

7. The constant relation of P_2O_5 to CaO in apatite (P_2O_5 : CaO : : 1 : 3.33).

8. The relation of CaO and (Mg,Fe)O in monoclinic pyroxene, diopside (CaO : (Mg,Fe)O : : 1 : 1).

9. The occurrence of (Mg,Fe)O both as metasilicate or orthosilicate, in hypersthene and olivine.

10. The frequent, but not invariable, relation between (Mg,Fe)O and available silica, whereby metasilicate, hypersthene, forms instead of orthosilicate, olivine, with sufficient available silica.

11. The occasional occurrence of a sodium metasilicate molecule, $Na_2O.SiO_2$, which enters into arfvedsonite in rocks in which K_2O and Na_2O are in excess of Al_2O_3 and Fe_2O_3.

12. The fact that, apart from apatite, the only common non-silico-aluminous, primary rock-making minerals are magnetite and ilmenite; the iron being the only element of the important ones which in rocks can crystallize without SiO_2 or Al_2O_3.

13. Finally the common occurrence of SiO_2, CaO and Na_2O in minerals of both the salic and femic groups, and their resulting interdependence.

CALCULATION OF THE NORM.

The method adopted by us of calculating the standard mineral composition is as follows:

1. Determine the molecular proportions of the chemical components of a rock as expressed by the complete analysis, by dividing the percentage weights of each component by its molecular weight.

2. Before undertaking the distribution of the chemical components as mineral molecules, small amounts of MnO and NiO are to be united with FeO, and of BaO and SrO with CaO; of Cr_2O_3 with Fe_2O_3, unless these unusual components occur in sufficient amounts to make their calculation as special mineral molecules desirable. These amounts are indicated in connection with examples of calculation given later.

3. Establish the fixed molecules by allotting:

a) to Cr_2O_3, if present in notable amount, FeO to satisfy the ratio Cr_2O_3 : FeO : : 1 : 1 for chromite;

b) to TiO_2 enough FeO to satisfy the ratio TiO_2 : FeO : : 1 : 1 for ilmenite. If there is excess of TiO_2, allot to it equal CaO for titanite or perofskite according to available silica, to be determined later. If there is still an excess of TiO_2 it is to be calculated as rutile;

c) to P_2O_5 allot enough CaO to satisfy the ratio P_2O_5 : CaO : : 1 : 3.33 for apatite. Allot F to satisfy CaO $= 0.33P_2O_5$;

d) to F not used in apatite allot CaO to form fluorite, CaO : F : : 1 : 2;

e) to Cl allot Na_2O in the ratio Cl_2 : $Na_2(O)$: : 1 : 1 for sodalite;

f) to SO_3 allot Na_2O in proportion SO_3 : Na_2O : : 1 : 1 for noselite;

g) to S allot FeO in proportion S : Fe(O) : : 2 : 1 for pyrite;

h) to CO_2 in undecomposed rocks allot CaO in the proportion 1 : 1 for calcite. CO_2 may occur in primary calcite and cancrinite. If these minerals are secondary, the CO_2 is to be neglected, since it is understood that analyses of decomposed rocks are not available for purposes of classification.

Having adjusted the minor, inflexible, molecules, there remain the more important but variable silicate molecules, which form the great part of the standard mineral composition, or *norm*, of most rocks.

4. To Al_2O_3 are allotted all the K_2O and Na_2O, not already disposed of, in the proportion of Al_2O_3 : $K_2O + Na_2O$: : 1 : 1 for alkali feldspathic and feldspathoid (lenad) molecules.

5. With excess of Al_2O_3, ($Al_2O_3 > K_2O + Na_2O$):

a) to extra Al_2O_3 allot CaO in proportion of Al_2O_3 : CaO :: 1 : 1 for anorthite molecules.

b) If there is further excess of Al_2O_3 it is to be considered as corundum, Al_2O_3.

It it is not advisable to calculate muscovite with excess of Al_2O_3 instead of corundum, since it requires a readjustment of orthoclase molecules, and muscovite may not occur in the rock, the extra Al_2O_3 entering alferric minerals. Its calculation is considered subsequently.

6. With insufficient Al_2O_3, ($Al_2O_3 < K_2O + Na_2O$):

a) Extra Na_2O is allotted to Fe_2O_3 in proportion Fe_2O_3 : Na_2O :: 1 : 1 for acmite molecules.

b) If there is still extra Na_2O it is set aside for a metasilicate molecule (Na_2SiO_3).

c) When there is an excess of K_2O over Al_2O_3 it is treated in the same manner. It is an extremely rare occurrence.

7. In working with reliable analyses in which Fe_2O_3 and FeO have been correctly determined:

a) To Fe_2O_3 is allotted excess of Na_2O under conditions 6, *a*).

b) To remaining Fe_2O_3 is allotted available FeO in equal proportions for magnetite.

c) If there is any excess of Fe_2O_3 it is calculated as hematite.

Analyses in which all the iron has been determined in one form of oxidation, when it occurs in two, are of little value when considerable iron is present. When the amount of iron is very small the analyses may still be used as a means of classifying the rock. For this purpose all the iron, if given as ferric oxide, is to be calculated as FeO, except that necessary to be allotted to Na_2O for acmite, and then used as below.

8. *a*) Extra CaO after the foregoing assignments is allotted to (Mg, Fe)O in proportion CaO : (Mg, Fe)O :: 1 : 1 for diopside molecules.

In all molecules where (Mg, Fe)O is present, MgO and FeO are to be used in the same proportions in which they are found

after FeO has been allotted to the molecules previously mentioned. That is, they are to be introduced into diopside, hypersthene and olivine with the same ratio between them.

b) If there is still an excess of CaO it is to be set aside for calcium metasilicate ($CaSiO_3$) or subsilicate ($4CaO.\ 3\ SiO_2$), equivalent to wollastonite or akermanite. Such extra CaO will in most cases actually enter garnet, an alferric mineral.

9. With insufficient CaO, ($CaO < (Mg, Fe)O$):

a) Extra (Mg, Fe)O is to be set aside for metasilicate or orthosilicate, hypersthene or olivine, according to the amount of SiO_2 present.

The allotment of SiO_2 to form silicates begins with the bases which occur with silica in but one proportion, and is carried on as follows:

10. To ZrO_2 allot SiO_2 in proportion of 1 : 1 for zircon.

11. To CaO and Al_2O_3 in anorthite is allotted equal SiO_2 to form $CaO.Al_2O_3.2SiO_2$.

12. To CaO and (Mg, Fe)O in diopside is allotted equal SiO_2 to form $CaO.(Mg, Fe)O.2SiO_2$.

13. To Na_2O and Fe_2O_3 in acmite is allotted SiO_2 to form $Na_2O.\ Fe_2O_3.4SiO_2$.

14. To Na_2O (or K_2O) set aside for metasilicate molecules allot SiO_2 to form $Na_2O.SiO_2$ or $K_2O.SiO_2$.

15. To Na_2O and Al_2O_3 in sufficient amount to form with NaCl sodalite, or with Na_2SO_4 noselite, is allotted SiO_2 to satisfy the formulas : $3(Na_2O.Al_2O_3\ 2SiO_2).2NaCl$, sodalite, $2(Na_2O.Al_2O_3.2SiO_2).Na_2SO_4$ noselite.

The allotment of silica to bases which may form two or more silicates, ortho-, meta- or polysilicate, is controlled in part by the amount of available silica, in part by the affinities of the bases for silica as explained below, in accordance with certain commonly observed facts, as follows:

a) Quartz does not occur with nephelite and leucite, that is, the feldspathic molecules will be polysilicates, orthoclase and albite, if there is sufficient available silica.

b) Of the feldspathoids (lenads), the metasilicates—leucite and analcite—are rarer than the orthosilicates, nephelite and the sodalites. Analcite is so rare as a primary mineral that it may be omitted from the discussion, and may be regarded as composed of albite and nephelite + 2 water. Nephelite is more frequently associated with orthoclase than leucite with albite, from which it appears that potassic feldspathic molecules become polysilicate when sodic ones form orthosilicate. If there is not enough available silica to form orthoclase, leucite forms.

c) The method is also based on the infrequent occurrence of orthorhombic pyroxene with the feldspathoids, and the frequent occurrence of olivine with these minerals. From which may be deduced the rule that the development of metasilicate or orthosilicate of (Mg, Fe)O is controlled in most cases by the available silica after satisfying the feldspathic molecules.

d) Finally, the occurrence of melilite (akermanite) in rocks free from the polysilicate feldspars and the metasilicate, hypersthene, indicates that this subsilicate mineral is produced because of insufficient silica to form the lowest normal silicates commonly developed in igneous rocks.

The order of affinity of the common rock-forming oxides for silica, which is well established by the foregoing and other facts, as well as by such investigations as those of Lagorio[1] and Morozewicz,[2] is as follows, beginning with that which has most affinity, K_2O, Na_2O, CaO, MgO, FeO. The oxides Al_2O_3 and Fe_2O_3 to some extent are analogous to SiO_2 and play in certain respects the rôle of acidic oxides.

The validity of this order is illustrated and confirmed by the following facts: K_2O and Na_2O alone form polysilicates (orthoclase and albite) with the ratios $(K, Na)_2O : SiO_2 :: 1 : 6$. They also form the metasilicates (leucite, analcite and acmite) with the ratio $(K,Na)_2O : SiO_2 :: 1 : 4$. Na_2O also forms the orthosilicate nephelite, as well as the minerals of the sodalite group, with the ratio $Na_2O : SiO_2 :: 1 : 2$. The corresponding

[1] TSCHENMAK'S *Min. Petr. Mitth.*, Vol. VIII, pp. 421 ff., 1887.

[2] *Ibid.*, Vol. XVIII, pp. 221 ff., 1899.

potash compound, kaliophilite, is rare and not a rock-making mineral, though K_2O enters into the composition of nephelite to some extent. If potash and soda are present and there is insufficient silica to form polysilicates of both, then as a general rule, K_2O takes all the silica it can get to form orthoclase, or orthoclase and leucite, the soda taking the rest to form nephelite, together with albite in some cases. The occurrence of K_2O in the micas appears at first thought to be an exception to this rule, but further consideration shows that in the muscovite molecule, $(H,K)_2O . Al_2O_3 ,2SiO_2$, when $H = 2K$, the SiO_2 is six times K_2O, as in orthoclase; and when $H = K$, the SiO_2 is four times K_2O, as in leucite.

CaO forms the orthosilicate anorthite with the ratio $CaO : SiO_2 :: 1 : 2$, and controls an amount of SiO_2 equal to itself in the wollastonite molecule. In akermanite the $CaO : SiO_2 :: 4 : 3$.

MgO and FeO can, at most, control only their own amounts of silica, in the hypersthene molecule, and also form the orthosilicate olivine, with the ratio $(Fe, Mg)O : SiO_2 :: 2 : 1$. Finally, FeO crystallizes out in non-siliceous and non-aluminous minerals, magnetite and ilmenite.

It is noteworthy that the order of affinity of these oxides for alumina is the same in relative order as that for silica. So K_2O forms muscovite with an excess of alumina over potash, the analagous paragonite being rare and only found in metamorphic rocks, Na_2O being slightly in excess of Al_2O_3 in the sodalites, CaO largely so (3 : 1) in garnet, and MgO and FeO having little affinity for it.

MgO and FeO can, it is true, form the non-siliceous, aluminous mineral, spinel, $RO. R_2O_3$.

In the calculation of the standard mineral composition the allotment of silica to the alternative molecules is, therefore, as follows:

16. To CaO set aside for wollastonite or akermanite is allotted tentatively SiO_2 to form wollastonite $(CaO . SiO_2)$.

17. To extra $(Mg,Fe)O$ is allotted SiO_2 to form orthosilicate, olivine $(2(Mg,Fe)O . SiO_2)$.

18. To Al_2O_3 and $K_2O + Na_2O$ is allotted SiO_2 to make polysilicate, orthoclase, albite $(K, Na)_2O.Al_2O_3.6\ SiO_2$.

a) If there is excess of SiO_2 it is added to the orthosilicate of (Mg, Fe)O to raise it to the metasilicate $(Mg,Fe)O.SiO_2$. If SiO_2 is insufficient to convert all the olivine into hypersthene it is distributed according to the following equations:

$$x + y = \text{molecules of (Mg,Fe)O.}$$
$$x + \frac{y}{2} = \text{available } SiO_2.$$

where x = hypersthene, y = olivine molecules.

b) Further excess of SiO_2 is to be allotted to TiO_2 and CaO to form titanite. These constituents remain as perofskite when there is no excess of SiO_2.

c) Further excess of SiO_2 is reckoned as quartz.

19. If there is insufficient SiO_2 to form polysilicate feldspar out of all the K_2O and Na_2O with Al_2O_3:

a) To $K_2O.Al_2O_3$ is allotted tentatively enough SiO_2 to form polysilicate, orthoclase $(K_2O.Al_2O_3.6SiO_2)$ and the remaining SiO_2 is distributed between albite and nephelite molecules by means of the equations:

$$x + y = \text{molecules of } Na_2O.$$
$$6x + 2y = \text{available } SiO_2.$$

where x = albite, and y = nephelite molecules.

b) If the available SiO_2 in case 15, *a*) is insufficient to form nephelite with the Na_2O, then enough SiO_2 is first allotted to the Na_2O to form nephelite and the remaining SiO_2 is distributed between orthoclase and leucite molecules by means of the equations:

$$x + y = \text{molecules of } K_2O.$$
$$6x + 4y = \text{available } SiO_2.$$

where x = orthoclase, and y = leucite molecules.

20. If there is insufficient SiO_2 to form leucite and nephelite with olivine it is necessary to reduce a sufficient number of molecules to form the subsilicate akermanite, $4CaO.3SiO_2$.

a) In case there is no wollastonite this is done after dis-

tributing SiO_2 tentatively to form leucite, nephelite and olivine and noting the deficit of SiO_2 by means of the equation:

$$y = \frac{1}{3} \text{ of the deficit of } SiO_2.$$

$$y = \text{molecules of akermanite. } (4CaO.3SiO_2).$$

CaO is to be taken from diopside, and the MgO and FeO so liberated are to be calculated as olivine.

b) In case an excess of CaO has been set aside for wollastonite this is first converted to akermanite by means of the equations: $y =$ the deficit of SiO_2.

$$y = \text{molecules of akermanite } (4CaO.3SiO_2).$$

c) If there are not sufficient molecules of wollastonite to satisfy the deficit of silica, recalculate the molecules of diopside and wollastonite so as to make olivine, diopside and akermanite by means of the formulæ.

$$\begin{aligned} 2x + 3y + \frac{z}{2} &= \text{available } SiO_2. \\ x + 4y \quad &= \text{molecules of CaO.} \\ x + \quad z &= \text{molecules of MgO + FeO.} \end{aligned}$$

Where $x =$ molecules of new diopside, $y =$ molecules of akermanite ($4CaO.3SiO_2$), and $z =$ molecules of olivine.

21. If there is still not enough SiO_2, all the CaO of the diopside and wollastonite must be calculated as akermanite, the (Mg, Fe)O being reckoned as olivine and the K_2O distributed between leucite and kaliophilite by the equations:

$$\begin{aligned} x + y &= \text{molecules of } K_2O. \\ 4x + 2y &= \text{available } SiO_2. \end{aligned}$$

where x is K_2O in leucite and $y = K_2O$ in kaliophilite.

22 In case there is insufficient SiO_2 and an excess of Al_2O_3 and (Mg,Fe)O, which might form aluminous spinel, an alferric mineral, the excess of Al_2O_3 is to be calculated as corundum, and the uncombined (Mg,Fe)O is to be estimated as femic minerals, being placed with the nonsilicate, mitic, group, magnetite, ilmenite, etc.

It will be noted that as a result of the methods given above the following minerals are not found together in the *norm*, standard mineral composition, of igneous rocks; in other

words, that the calculation of the former of each pair precludes that of the latter, and conversely.

With quartz there will be no nephelite, leucite or olivine.
With hypersthene there will be no nephelite or leucite.
With corundum there will be no diopside or acmite.
With anorthite there will be no acmite.
With wollastonite there will be no hypersthene or olivine.
With leucite there will be no albite.

Percentage weights of minerals.—Having estimated the relative number of molecules of the various mineral components, their relative masses may be obtained by multiplying each by the molecular weight. This is readily accomplished by means of tables, both for finding the molecular proportions corresponding to percentages of the chemical components given in analyses, such as those lately published by J. F. Kemp[1] and others, for finding the percentage weights of the minerals with constant composition when their molecular proportions have been calculated. The weights of minerals like olivine and pyroxene in which the component (Mg, Fe) O is variable must be calculated from the proportions of MgO and FeO present in the rock after deduction of FeO allotted to magnetite and ilmenite, the same ratio between these oxides being used for each kind of molecule containing both of them. The weights of diopside, hypersthene and olivine, in which MgO and FeO occur in varying amounts, may be computed from the sums of the simple molecules $CaSiO_3$, $MgSiO_3$, $FeSiO_3$, and Mg_2SiO_4, Fe_2SiO_4.

Tables for finding the molecular proportions of the constituent oxides, and those for the percentage weights of the standard minerals will be found in the reprint of this paper, already alluded to.

EXAMPLES OF CALCULATIONS.

It will be useful to give some examples illustrative of the method of calculation and of the various possibilities, selected from several thousand calculated by us. To simplify

[1] KEMP, J. F., "The Recalculation of the Chemical Analyses of Rocks," *School of Mines Quarterly*, Vol. XXII, pp. 75–88.

them, the molecular weights of the minerals which have fixed molecules, as orthoclase, anorthite, magnetite, etc., are multiplied by the number of molecules of the unit oxide in each case to arrive at the percentage weight.

For general purposes very small amounts of the component oxides may be neglected. But for close work it is necessary to take into account even small percentages of P_2O_5, TiO_2, SO_3, etc., that is, where any one of them amounts to two units in the scale of molecular proportions; when $P_2O_5 = 0.28$, $TiO_2 = 0.16$, $SO_3 = 0.16$, $CO_2 = 0.08$, $Cl = 0.07$, $F = 0.04$ of a per cent.

The introduction of these into the calculation is important in proportion as the amounts of the bases with which they combine are small in the rock.

A check on the results is furnished by the agreement of the sum of the calculated mineral components and the components not included in the calculation with the sum total of the analysis. This check cannot be absolutely exact because of errors in the determination of the last decimal figure in the calculation of each component throughout the process.

The rocks chosen to illustrate the method represent several cases. That of the toscanose (granodiorite), Table I, is the simplest case. Al_2O_3 and SiO_2, being in excess, yield normative corundum and quartz; the femic silicate being hypersthene.

The hessose (amphibole-gabbro), Table II, illustrates the method of adjusting SiO_2 between hypersthene and olivine.

The nordmarkose (litchfieldite), Table III, illustrates the method of distributing SiO_2 between albite and nephelite after reckoning the femic silicate as olivine. All the Na_2O is first allotted to Al_2O_3, and SiO_2 is allotted to orthoclase, anorthite, and olivine; the remainder, 0.680 mol., is distributed according to the formulæ.

In the case of the laurdalose (laurdalite), Table IV, insufficient Al_2O_3 necessitates the formation of acmite molecules. After allotting SiO_2 to orthoclase, acmite, diopside, and olivine, the remainder, 0.522 mol., is distributed between albite and nephelite.

The vesuvose-albanose (leucitite), Table V, illustrates the case in which akermanite (melilite) is required to satisfy the calculation. After allotting SiO_2 to leucite, nephelite, anorthite, diopside, and olivine, there is a deficit of 0.069 mol. SiO_2. This is adjusted by the introduction of akermanite according to the formula, and the recalculation of diopside and olivine. It also illustrates the case of an intermediate rock, between Classes I and II.

TABLE I.

TOSCANOSE (GRANODIORITE) EL CAPITAN, YOSEMITE VALLEY, CAL.

Bull. 168, U. S. Geol. Surv., p. 208.

	Per cent.	Mol.	Ilm.	Mag.	Orth.	Alb.	An.	Cor.	Hyp.	Quartz.
SiO_2 ...	71.08	1.185	....	....	258	342	94	....	27	464
Al_2O_3 ..	15.90	.156	....	....	43	57	47	9	....	....
Fe_2O_3 .	.62	.004	....	4	....	....	....	....	....	....
FeO ...	1.31	.018	3	4	....	....	....	....	11	....
MgO...	.54	.014	....	....	....	....	....	....	14	....
CaO ...	2.60	.047	....	....	....	....	47	....	....	....
Na_2O ..	3.54	.057	....	....	....	57	....	....	....	....
K_2O ...	4.08	.043	....	....	43	....	....	....	....	....
H_2O+	.30	....	....	....	....	....	....	....	....	....
H_2O-.	none	....	....	....	....	....	....	....	....	....
CO_2 ...	tr	....	....	....	....	....	....	....	....	....
TiO_2...	.22	.003	3	....	....	....	....	....	....	....
P_2O_5 ..	.10	.000	....	....	....	....	....	....	....	...
SO_3 ...	none	....	....	....	....	....	....	....	....	....
Cl	.02	.000	....	....	....	....	....	....	....	....
MnO...	.15	.002	....	....	....	....	....	....	2	...
BaO ...	.04	.000	....	....	....	....	....	....	....	....
SrO	.02	.000	....	....	....	....	....	....	....	....
ZrO_2...	.08	.000	....	....	....	....	....	....	....	....
	100.60									

FORMULA.	MOL. WT.		NORM.				
SiO_2	464 × 60	= quartz	= 27.84	Q	27.84	Sal	95.61
$K_2O.Al_2O_3.6SiO_2$	43 × 556	= orthoclase	= 23.91				
$Na_2O.Al_2O_3.6SiO_2$	57 × 524	= albite	= 29.87	F	66.85		
$CaO.Al_2O_3 2.SiO_2$	47 × 278	= anorthite	= 13.07				
Al_2O_3	9 × 102	= corundum	= .92	C	.92		
$MgO.SiO_2$	14 × 100	= hypersthene	= 3.11	P	3.11	Fem	4.49
(Fe, Mn)$O.SiO_2$	13 × 132						
$FeO.Fe_2O_3$	4 × 232	= magnetite	= .93	M	1.38		
$FeO.TiO_2$	3 × 152	= ilmenite	= .45				
			100.10				

CLASS I. $\frac{\text{Sal}}{\text{Fem}} = \frac{95.6}{4.5} > \frac{7}{1}$ *Persalane.*

ORDER 4. $\frac{\text{F}}{\text{Q}} = \frac{66.8}{27.8} > \frac{5}{3} < \frac{7}{1}$ *Britannare.*

RANG 2. $\frac{K_2O' + Na_2O'}{CaO'} = \frac{100}{47} > \frac{5}{3} < \frac{7}{1}$ *Toscanase.*

SUBRANG 3. $\frac{K_2O'}{Na_2O'} = \frac{43}{57} < \frac{5}{3} > \frac{3}{5}$ *Toscanose.*

TABLE II.

HESSOSE (AMPHIBOLE GABBRO) BEAVER CREEK, BIG TREES QUADRANGLE, CAL.

A. J. S., Vol. VIII (1899), p. 297; *Bull.*, *168*, U. S. G. S., p. 206.

	Per Cent.	Mol.	Apat.	Ilm.	Mag.	Orth.	Alb.	An.	Diop.	Rem'der.	Hyp.	Oliv.
SiO_2	47.27	.788	..	..	..	12	264	306	118	88	37	51
Al_2O_3 ...	20.82	.204	..	..	..	2	44	158	..	..	..	..
Fe_2O_3 ...	1.85	.011	..	..	11	..	..	..	..	..	..	..
FeO	4.26	.059	..	11	11	..	..	..	59	139	37	102
MgO	6.44	.161	..	..	..	..	..	..				
CaO	13.02	.232	15	..	..	..	..	158	59	..	..	..
Na_2O....	2.75	.044	..	..	..	..	44	..	..	..	..	..
K_2O	.22	.002	..	..	..	2	..	..	..	..	..	..
H_2O+ ..	1.27	....	..	..	..	..	..	..	..	..	..	..
H_2O- ..	.08	....	..	..	..	..	..	..	..	..	..	..
TiO_2	.92	.011	..	11	..	..	..	..	..	..	..	..
P_2O_5	.74	.005	5	..	..	..	..	..	..	..	..	..
Cl	tr	....	..	..	..	..	..	..	..	..	..	..
Cr_2O_3 ...	tr	....	..	..	..	..	..	..	..	..	..	..
MnO	tr	....	..	..	..	..	..	..	..	..	..	..
SrO	tr	....	..	..	..	..	..	..	..	..	..	..
V_2O_3....	.02	....	..	..	..	..	..	..	..	..	..	..
FeS_2	.20	...	..	..	..	..	..	..	..	..	..	..
	99.86											

$$x + \frac{y}{2} = 88\ SiO_2$$

$$x + y = 139\ (Mg, Fe)\ O$$

$$y = 102$$

$$x = 37$$

FORMULA.	MOL. WT.		NORM.				
$K_2O.Al_2O_3.6SiO_2$	2 × 556	= orthoclase =	1.11	F	68.09	Sal 68.09	
$Na_2O.Al_2O_3.6SiO_2$	44 × 524	= albite =	23.06				
$CaO.Al_2O_3.2SiO_2$	158 × 278	= anorthite =	43.92				
$CaO.SiO_2$	59 × 116	= diopside =	13.10	P + O	24.77		Fem 30.74
$MgO.SiO_2$	48 × 100						
$FeO.SiO_2$	11 × 32						
$MgO\ SiO_2$	30 × 100	= hypersthene =	3.92				
$FeO.SiO_2$	7 × 132						
$2MgO.SiO_2$	83 × 70	= olivine =	7.75				
$2FeO.SiO_2$	19 × 102						
$FeO.Fe_2O_3$	11 × 232	= magnetite =	2.55	M	4.22		
$FeO.TiO_2$	11 × 152	= ilmenite =	1.67				
$3CaO.P_2O_5$	5 × 310	= apatite =	1.55	A	1.75		
FeS_2		pyrite =	.20				
		etc. =	1.37				
			100.20				

CLASS II.

$$\frac{Sal}{Fem} = \frac{68.09}{30.74} < \frac{7}{1} > \frac{5}{3}$$

Dosalane.

ORDER 5.

$$\frac{F}{Q} = \frac{68.09}{0} > \frac{7}{1}$$

Germanare.

RANG 4.

$$\frac{K_2O' + Na_2O'}{CaO'} = \frac{46}{158} < \frac{3}{5} > \frac{1}{7}$$

Hessose.

SUBRANG 3.

$$\frac{K_2O'}{Na_2O'} = \frac{2}{44} < \frac{1}{7}$$

Hessose.

TABLE III.

NORDMARKOSE (LITCHFIELDITE), LITCHFIELD, ME.

Bull. 168, U. S. Geol. Surv., p. 21.

	Per cent.	Mol.	Orth.	Alb.	Nep.	An.	Cor.	Mag.	Oliv.
				612	68				
SiO_2	60.39	1.006	300	680		10	..	..	16
				102	34				
Al_2O_3	22.57	.221	50	136		5	30	..	..
Fe_2O_3	.42	.003	...	...	..	..	..	3	..
FeO	2.26	.030	...	...	..	..	..	3	27
MgO......	.13	.003	...	...	..	..	..	..	3
CaO.......	.32	.005	...	...	..	5	..	..	..
				102	34				
Na_2O	8.44	.136	...	136		..	..	..	..
K_2O	4.77	.050	50	...	..	..	..	..	..
H_2O+ H_2O- ..	.57	....	...	...	..	..	..	..	..
MnO......	.08	.001	...	...	..	..	..	..	1
	99.95								

$$1.006-(0.300 + 0.010 + 0.016)=0.680$$
$$6x + 2y = 680\ (SiO_2)$$
$$x + y = 136\ (Na_2O)$$
$$x = 102$$
$$y = 34$$

In the rock the extra Al_2O_3 enters mica, combining with the olivine and magnetite molecules and because of low magnesia making lepidomelane.

FORMULA.	MOL. WT.	NORM.				
$K_2O.Al_2O_3.6SiO_2$ - - -	50 × 556	= orthoclase =	27.80	F	Sal	95.35
$Na_2O.Al_2O_3.6SiO_2$ - -	102 × 524	= albite =	53.45			
$CaO.Al_2O_3.2SiO_2$ - - -	5 × 278	= anorthite =	1.39			
$Na_2O.Al_2O_3.2SiO_2$ - -	34 × 284	= nephelite =	9.66	L		
Al_2O_3. - - - - - -	30 × 102	= corundum =	3.06	C		
$FeO.Fe_2O_3$ - - - - -	3 × 232	= magnetite =	.70	M	Fem	3.81
$2MgO.SiO_2$ - - - - -	3 × 70	= olivine =	3.11	O		
$2FeO.SiO_2$ - - - - -	28 × 102					
		H_2O =	.57			
			99.73			

CLASS I.	ORDER 5.	RANG I.	SUBRANG 4.
$\frac{Sal}{Fem} = \frac{95.35}{3.81} > \frac{7}{1}$	$\frac{F}{L} = \frac{82.64}{9.66} > \frac{7}{1}$	$\frac{K_2O' + Na_2O'}{CaO'} = \frac{186}{3} > \frac{7}{1}$	$\frac{K_2O'}{Na_2O'} = \frac{50}{136} < \frac{3}{5} > \frac{1}{7}$
Persalane.	*Canadare.*	*Nordmarkase.*	*Nordmarkose.*

TABLE IV.

LAURDALOSE (LAUDALITE), WEST OF POLLEN, LAUGENDAL, NORWAY.

BRÖGGER, W. C., *Die Eruptivgesteine des Christiania Gebietes*, Vol. III, p. 19.

	Per cent.	Mol.	Ap.	Ilm.	Orth.	Alb.	Nep.	Acm.	Mag.	Diop.	Oliv.
						366	156				
SiO_2	56.35	.939	..	..	336	522		16	..	62	3
						61	78				
Al_2O_3 ...	19.85	.195	..	..	56	139		..	..	..	..
Fe_2O_3 ...	1.91	.012	..	..	...	...	...	4	8	..	..
FeO	2.03	.028	..	12	...	...	...	..	8	7	1
MgO	1.17	.029	..	..	...	...	...	..	..	24	5
CaO	2.60	.046	15	..	...	...	...	..	..	31	..
						61	78				
Na_2O....	8.89	.143	..	..	...	139		4	..	..	..
K_2O.....	5.31	.056	..	..	56	...	...	..	..	..	..
H_2O	.70	....	..	..	...	...	...	..	..	..	..
TiO_2	1.00	.012	..	12	...	...	...	..	..	..	..
P_2O_5	.67	.005	5	..	...	...	...	..	..	..	..
	100.68										

$$6x + 2y = 522\ (SiO_2)$$
$$x + y = 139\ (Na_2O)$$
$$x = 61$$
$$y = 78$$

FORMULA.	MOL. WT.		NORM.				
$K_2O.Al_2O_3.6SiO_2$	56×556	= orthoclase =	31.14	F	63.10	Sal	85.25
$Na_2O.Al_2O_3.6SiO_2$	61×524	= albite =	31.96				
$Na_2O.Al_2O_3.2SiO_2$	78×284	= nephelite =	22.15	L	22.15		
$Na_2O.Fe_2O_3.4SiO_2$	4×462	= acmite =	1.85	P	8.77	Fem	14.45
$CaO.SiO_2$	31×116						
$MgO.SiO_2$	24×100	= diopside =	6.92				
$FeO.SiO_2$	7×132						
$2MgO.SiO_2$	5×70	= olivine =	.46	O	.46		
$2FeO.SiO_2$	1×102						
$FeO.Fe_2O_3$	8×232	= magnetite =	1.86	M	3.68		
$FeO.TiO_2$	12×152	= ilmenite =	1.82				
$3CaO.P_2O_5$	5×310	= apatite =	1.55	A	1.55		
		H_2O =	.70				
			100.41				

CLASS II. $\frac{\text{Sal}}{\text{Fem}} = \frac{85.25}{14.45} < \frac{7}{1} > \frac{5}{3}$ *Dosalane.*

ORDER 6. $\frac{F}{L} = \frac{63.10}{22.15} < \frac{7}{1} > \frac{5}{3}$ *Norgare.*

RANG 1. $\frac{K_2O' + Na_2O'}{CaO'} = \frac{195}{0} > \frac{7}{1}$ *Laurdalase.*

SUBRANG 4. $\frac{K_2O'}{Na_2O'} = \frac{56}{139} < \frac{3}{5} > \frac{1}{7}$ *Laurdalose.*

TABLE V.

VESUVOSE-ALBANOSE (LEUCITITE). CAPO DI BOVE, ITALY.

A. J. S., Vol. IX (1900), p. 56.

	Per cent.	Mol.	Ilm.	Leuc.	Nep.	An.	Mag.	Tentative. Diop.	Tentative. Oliv.	Deficit.	Final. Ak.[1]	Final. Diop.	Final. Oliv.
SiO_2	45.99	.767	....	376	70	78	....	298	14	69	69	114	60
Al_2O_3	17.12	.168	....	94	35	39	....	....	....	....	....	....	....
Fe_2O_3	4.17	.026	....	....	....	....	26	....	....	....	....	....	....
FeO	5.38	.075	5	....	....	....	26	37	7	....	....	14	30
MgO	5.30	.133	....	....	....	....	....	112	21	....	....	43	90
CaO	10.47	.187	....	....	....	39	....	148	....	....	92	56	....
Na_2O	2.18	.035	....	....	35	....	....	....	....	....	....	....	....
K_2O	8.97	.094	....	94	....	....	....	....	....	....	....	....	....
H_2O	.45	....	....	....	....	....	....	....	....	....	....	....	....
TiO_2	.37	.005	5	....	....	....	....	....	....	....	....	....	....
MnO	tr	....	....	....	....	....	....	....	....	....	....	....	....
BaO	.25	.001	....	....	....	....	....	1	....	....	....	1	....
SrO	none	....	....	....	....	....	....	....	....	....	....	....	....
	100.65	....	....	....	....	....	....	....	....	....	....	....	....

[1] Mol. of akermanite $= y = \frac{69}{3} = 23$.

FORMULA.	MOL. WT.		NORM.		
$K_2O.Al_2O_3.4SiO_2$	94×436	= leucite =	40.98	L = 50.92	Sal 61.76
$Na_2O.Al_2O_3 2SiO_2$	35×284	= nephelite =	9.94		
$CaO.Al_2O_3.2SiO_2$	39×278	= anorthite =	10.84	F = 10.84	
$CaO.SiO_2$	57×116	= diopside =	12.76	P = 12.76	Fem 38.20
$MgO.SiO_2$	43×100				
$FeO.SiO_2$	14×132				
$2MgO.SiO_2$	90×70	= olivine =	9.36	O = 18.65	
$2FeO.SiO_2$	30×102				
$4CaO.3SiO_2$	23×404	= akermanite =	9.29		
$FeO.Fe_2O_3$	26×232	= magnetite =	6.03	M = 6.79	
$FeO.TiO_2$	5×152	= ilmenite =	.76		
		H_2O	.45		
			100.41		

CLASS III.

$$\frac{\text{Sal}}{\text{Fem}} = \frac{61.76}{38.20} < \frac{5}{3} > \frac{3}{5}$$

Dosalane-salfemane.

ORDER 6.

$$\frac{F}{L} = \frac{10.84}{50.92} < \frac{3}{5} > \frac{1}{7}$$

Campanare-bohemare.

RANG 2.

$$\frac{K_2O' + Na_2O'}{CaO'} = \frac{129}{39} < \frac{7}{1} > \frac{5}{3}$$

Vesuvase-albanase.

SUBRANG 2.

$$\frac{K_2O'}{Na_2O'} = \frac{94}{35} < \frac{7}{1} > \frac{5}{3}$$

Vesuvose albanose.

The janeirose (pseudo-leucite-sodalite-tinguaite), Table VI, illustrates the method of calculating leucite and orthoclase, as well as sodalite and noselite. After allotting SiO_2 to nephelite, acmite, diopside, and olivine, the remainder of SiO_2 is 0.546 mol.

TABLE VI.

JANEIROSE (PSEUDO-LEUCITE-SODALITE-TINGUAITE) BEAVER CREEK, BEARPAW MOUNTAINS, MONT.

Bull. 168, U. S. Geol. Surv., p. 136.

	Per cent.	Mol.	Ilm.	Fluor.	NaCl.	Na_2SO_4.	Calcite.	Orth.	Leuc.	Nep.[1]	Acm.	Diop.	Oliv.
								390	156				
SiO_2 .	51.93	.866	..	..	..	..	..	546		192	88	38	2
								65	39				
Al_2O_3	20.29	.200	..	..	..	..	..	104		96	..	..	..
Fe_2O_3	3.59	.022	..	..	..	..	..	..	..	..	22	..	..
FeO ..	1.20	.018	2	..	..	..	..	..	..	..	..	14	2
MgO ..	.22	.006	..	..	..	..	..	..	..	..	..	5	1
CaO ..	1.65	.030	..	7	..	..	6	..	..	..	..	17	..
Na_2O .	8.49	.137	..	..	10	9	..	..	..	96	22	..	..
								65	39				..
K_2O ..	9.81	.104	..	..	..	..	..	104		..	..	..	..
H_2O+	.10	....	..	..	..	..	..	..	..	..	..	..	..
H_2O-	.99	....	..	..	..	..	..	..	..	..	..	..	..
TiO_2 ..	.20	.002	2	..	..	..	..	..	..	..	..	..	..
P_2O_5 .	.06	.000	..	..	..	..	..	..	..	..	..	..	..
SrO ..	.07	.001	..	..	..	..	..	..	..	..	..	1	..
BaO ..	.09	.001	..	..	..	..	..	..	..	..	..	1	..
SO_3 ..	.67	.009	..	..	..	9	..	..	..	..	..	..	..
CO_2 ..	.25	.006	..	..	..	..	6	..	..	..	..	..	..
Cl....	.70	.020	..	..	20	..	..	..	..	..	..	..	..
F	.27	.014	..	14	..	..	..	..	..	..	..	..	..
		....	..	..	..	..	..	..	..	..	..	..	..
	100.58	....	..	..	..	..	..	..	..	..	..	..	..
	.27	....	..	..	..	..	..	..	..	..	..	..	..
		....	..	..	..	..	..	..	..	..	..	..	..
	100.31	....	..	..	..	..	..	..	..	..	..	..	..

[1] For nephelite, sodalite, and noselite.

$$6x + 4y = 546\ (SiO_2)$$
$$x + y = 104\ (K_2O)$$
$$x = 65$$
$$y = 39$$

FORMULA.	MOL. WT.		NORM.			
$K_2O.Al_2O_3.6SiO_2$	65 × 556	= orthoclase =	36.14	F	36.14	Sal. 82.75
$K_2O.Al_2O_3.4SiO_2$	39 × 436	= leucite=	17.00	L	46.61	
$Na_2O.Al_2O_3.2SiO_2$	48 × 284	= nephelite =	13.63			
$3(Na_2O.Al_2O_3.2SiO_2)2(NaCl)$	10 × 969	= sodalite	9.69			
$2(Na_2O.Al_2O_3.2SiO_2)Na_2SO_4$	9 × 699	= noselite	6.29			
$Na_2O.Fe_2O_3.4SiO_2$	22 × 462	acmite	10.16	P	14.48	Fem. 15.60
$CaO.SiO_2$	17 × 116	diopside	4.32			
$MgO.SiO_2$	5 × 100					
$FeO.SiO_2$	14 × 132					
$2MgO.SiO_2$	1 × 70	olivine	.27	O	.27	
$2FeO.SiO_2$	2 × 102					
$FeO.TiO_2$	2 × 152	ilmenite	.30	M	.30	
CaF_2	7 × 78	fluorite	.55	A	.55	
$CaO.CO_2$	6 × 100	calcite	.60			
		H_2O	1.09			
			100.04			

CLASS II.	ORDER 7.	RANG I.	SUBRANG 3.
$\frac{\text{Sal}}{\text{Fem}}=\frac{82.75}{15.60}<\frac{7}{1}>\frac{5}{3}$	$\frac{\text{F}}{\text{L}}=\frac{36.14}{46.61}<\frac{5}{3}>\frac{3}{5}$	$\frac{K_2O'+Na_2O'}{CaO'}=\frac{219}{0}>\frac{7}{1}$	$\frac{K_2O'}{Na_2O'}=\frac{104}{115}<\frac{5}{3}>\frac{3}{5}$
Dosalane.	*Italare.*	*Lujavrase.*	*Janeirose.*

The calculation of the norm from the mode.— Having described the process by which the norm may be calculated from the chemical analysis of a rock, there remains the discussion of the process by which it may be calculated directly from the actual mineral composition of the rock without having the chemical analysis.

The first requisite in this case is a knowledge of the actual mineral composition of a particular rock; and it is evident that not every rock is sufficiently well crystallized to permit even an approximate estimate of the kinds and quantities of all the minerals present. Consequently there are very many rocks in which the norm cannot be calculated directly from the rock without recourse to a chemical analysis. These are partly glassy rocks, and those that are so fine-grained that the individual mineral components cannot be identified and measured.

But it is possible with some rocks to determine very closely the proportions of the minerals present in them. Such rocks are holocrystalline, and the crystals are sufficiently large to permit their individuality and outline to be recognized. With such rocks the method of determining the quantity of all the mineral components is as follows:

Estimate by accurate measurement the volumetric proportions of all the component minerals. This may be accomplished by measuring with a micrometer the diameters of each crystal in lines across thin sections of a rock, care being taken to measure a distance at least one hundred times the average grain of the rock.[1] The proportions found for the lengths of diameters of the various components will correspond to those of their volumes. Several other methods have been devised which are less accurate and need not be described here.

The volumetric proportions are to be reduced to relative masses by multiplying the volume of each mineral by its specific gravity and reducing the total to one hundred parts.

[1] ROSIWAL, *Verh. Wien. Geol. Reichs-Anst.*, Vol. XXXII, pp. 143 ff., 1898.

Accurate quantitative determination of the mineral components of rocks by optical methods is difficult with coarse-grained and coarsely porphyritic rocks as well as with extremely fine-grained ones. When the rock contains large crystals a comparatively large area of it must be measured to obtain correct proportions of the component minerals. A few thin sections are not adequate. The measurements must be made megascopically. The same is true when there are large phenocrysts. A sufficiently large area of surface must be measured to furnish a correct estimate of the relative proportions of the several kinds of phenocrysts and the groundmass. Subsequently the groundmass may be studied and measured with a microscope and the two sets of measurements combined.

In very fine-grained rocks, where the kinds of minerals composing them can all be identified, the accuracy of measurements of the diameters of crystals with a microscope is affected by the overlapping of crystals within the section, and it is found by experience that the amount of the colored crystals is overestimated, while that of the colorless ones is underestimated. This is particularly the case where the thickness of crystals is a fraction of the thickness of the rock section, as with microlites and minute inclusions. It will be necessary to determine corrections to be applied in such cases by working on microcrystalline or microlitic rocks whose chemical composition has been determined.

If all of the minerals actually present in a holocrystalline rock are standard minerals, salic or femic, there may still be uncertainty as to the norm, since the proportions of the standard minerals actually developed may not accord with those constituting the norm. In all cases it is necessary to calculate the norm from the actual mineral composition quantitatively determined by estimating the chemical composition of the rock from that of each of its component minerals, and from this analysis deducing the norm as in the first method described.

This involves the determination of the chemical composition of the actual minerals present in the rock. For a certain num-

ber this may be based on optical investigation. The composition of minerals with constant or comparatively simple molecules may be taken as that of the ideal molecule, as, for example, in such minerals as quartz, orthoclase, albite, anorthite, leucite, nephelite, apatite, zircon, titanite, etc.

The proportions of the chemical components reckoned as oxides belonging to each of these minerals must be multiplied by the percentage weight of each mineral to furnish the chemical components of the whole rock. Thus 35 per cent. of quartz = 35 per cent. of SiO_2; 10 per cent. of orthoclase = 6.47 per cent. of SiO_2, 1.83 per cent. Al_2O_3, 1.69 per cent. K_2O.

When the mineral has no fixed chemical molecule, as, for example, olivine, in which Mg and Fe are variable, it is necessary to consider the composition most likely to obtain for the mineral in a rock of about the character of the one under investigation, or to observe more specifically the optical properties of the mineral where these are characteristic of the chemical composition.

For the plagioclase feldspars the optical properties have been elaborately investigated and are well known. It is necessary to determine as accurately as possibly by Michel-Lévy[1] methods, aided by Becke's[2] method, the composition of the striated feldspars, noting the variation in zones, and estimating approximately the average composition of the crystals. The ratios of Ab to An must be transposed into ratios between Na_2O and CaO by halving the value of Ab. For the reason that Ab stands for the formula $NaAlSi_3O_8$ and An for the formula $CaAl_2Si_2O_8$. In the first there is only one Na, hence Ab : An : : Na : Ca. When we express the composition of albite by $Na_2O.Al_2O_3.6SiO_2$, we are using 2Ab. And in estimating Na_2O from the albite combined with anorthite in a plagioclase feldspar we obtain one-half as many molecules of Na_2O as we have Ab derived from the familiar symbol of a plagioclase, Ab_nAn_m.

[1] *Étude sur la détermination des feldspaths* (Paris), 1re fasicule, 1894; 2me fasicule, 1896.

[2] *Sitzungsb. Akad. Wiss. Wien.*, Vol. CII, Part I, pp. 358–76, 1893.

A less precise method may be used, which is sufficiently accurate considering the inaccuracy of the approximation to the average composition of zonally built feldspars, namely, to apply the ratio Ab / An obtained optically directly to the percentage weights of plagioclase. Thus 50 per cent. of plagioclase, whose average composition has been estimated at Ab_3An_2, may be separated into 30 per cent. albite and 20 per cent. anorthite with approximate correctness.

In the case of hornblende, augite, and mica, the color and optical properties are undoubtedly equally characteristic, but they have not received sufficient attention to permit of the same direct application. They are, however, guides to the choice of typical formulas or chemical analyses, which may be used temporarily in place of more exact methods.

For this purpose tables have been arranged giving the chemical analyses of certain rock-making alferric minerals, and also the analyses of the rocks in which these minerals occur. From these it is possible to select cases corresponding more or less closely to those in the rock whose norm is to be determined. For it appears from data already at hand that the chemical composition of each mineral in a rock bears such a relation to the chemical composition of the whole rock, that minerals of the same kind, for example the hornblendes, when they occur in similar rocks have very nearly the same composition. The compositions of the hornblendes and micas in the granodiorite of the Sierra Nevada, California, and of those in the very similar quartz-monzonite of Butte, Montana, are nearly the same.

For minerals with variable composition, then, select from Tables of Analyses the analysis of the mineral corresponding most closely to the one in the rock in question, considering both its optical characters and the general character of the rock in which it occurs, and reduce its several chemical constituents to the proper amount by multiplying by the percentage of the mineral as determined from the rock.

Having reduced each mineral to its chemical constituents

the sum of the constituents will represent the chemical composition of the rock. From this the salic and femic minerals may be calculated as in the first instance, and the norm determined.

In many cases it will not be necessary to reduce all of the minerals to their chemical constituents in order to determine the norm. For the minerals may be largely salic or femic as they occur in the rock. This is the case with the feldspars, feldspathoids (lenads), and quartz, with orthorhombic pyroxenes, olivine, diopside, magnetite, etc.

It is chiefly the aluminous ferromagnesian minerals that require reduction. And for first approximations the proportions of salic and femic constituents contained in these minerals are given in Tables XII, XIII, and XIV at the end of this Part.

From these it is seen that in aluminous pyroxenes the proportion of the salic component is often 0.10, and does not exceed 0.23. The femic component is 0.90 in most cases, and rarely 0.77.

For hornblende and closely related amphiboles the salic component is from 0.20 to 0.34, and in the more sodic amphiboles it is about 0.10.

For micas the two components are nearly equal, that is, 0.50 each.

When the amounts of salic and femic components are known the Class of the rock is established. For rocks of the first three Classes the next step is the determination of the relative amounts of quartz, feldspar, and feldspathoid. For persalane rocks this is comparatively simple, since the other minerals are present in small amounts. But as the amount of mica, amphibole, and augite increases it becomes necessary to determine more accurately the nature of the salic component involved in each, in order to adjust the silica before reckoning the proportions of quartz, feldspar, or feldspathoids. In such cases the first method must be followed, or the aluminous ferromagnesian minerals must be resolved into aluminous and non-aluminous portions and the silica adjusted to these portions and to the

other salic and femic components, according to the method given for calculating the standard minerals.

The determinations of Rang and Subrang as well as of Grad and Subgrad follow the calculation of the chemical components.

THE CALCULATION OF THE MODE FROM THE CHEMICAL ANALYSIS OF A ROCK.

This is often desired in order to compare the two, and to determine the amount of the chemical composition of some of the component minerals, not otherwise determinable.

But it is evident that the knowledge of the actual minerals present in the rock cannot be learned directly from the chemical analysis, since various mineral combinations may be formed within certain limits. It is therefore necessary to determine the presence of these minerals by a study of the rock, and this involves microscopical investigation in nearly all cases. This has generally meant the simple enumeration of the kinds of minerals present, with the crudest statement of their relative proportions.

In some instances this would furnish data enough for the solution of the problem, but it is clear that such cases must be those in which all the minerals present are salic and femic, without intermediate, alferric, kinds, or those cases in which the alferric minerals are developed to their limit, as for example, hornblende present to the exclusion of diopside, or to the exclusion of hypersthene and olivine; biotite present to the exclusion of hypersthene and olivine, or to the exclusion of potash-feldspathic minerals, or to the exhaustion of available alumina.

Under such circumstances it would be possible to calculate the composition and proportions of the actual minerals. But even in these cases the variable chemical character of amphiboles and micas renders the solution of the problem untrustworthy unless the composition of the particular amphibole or mica be known exactly or approximately.

This involves the separation and analysis of one or both of these minerals, or the reasonable assumption that they have

approximately the same composition as other amphiboles and micas which have been analyzed.

Further consideration of the problem will convince one that where augites, amphiboles, and micas occur with femic minerals, such as diopside, hypersthene, and olivine, the problem cannot be solved by simply determining the kinds of minerals present in the rock. The algebraic equations involve too many unknown quantities. In other words, there may be variable amounts of the same minerals developed from chemically similar magmas. It becomes necessary then to determine the relative amounts of several of these minerals, according to the number of them, in order to reduce the number of unknown quantities in the algebraic equations. Then it is possible, with part of the problem solved by microscopical study, to complete it by estimating the remaining factors from the chemical analysis of the rock. That is to say, in most cases the microscopical and chemical methods must supplement one another.

Thus it is possible to calculate the probable composition of a hornblende in a given rock when all the other minerals have comparatively simple, or fixed, molecules, and when the quantity of the hornblende has been determined optically. In another case, if hornblende has been separated from the rock and analyzed, it is possible to calculate the probable composition of a biotite present, when the proportions of these two minerals are known, and the other minerals in the rock have fixed molecules.

The same process may be used to determine the composition of the groundmass, when the character and percentages of the phenocrysts have been determined.

The method of calculation, which is illustrated by the case of the Butte granite given on a subsequent page, may be stated as follows:

Starting with the chemical analysis of the rock, reduce it to molecular proportions by dividing the percentage of each chemical component by its molecular weight.

Deduct from these molecules the molecules belonging to such minerals as have been chemically and quantitatively determined.

The remaining oxide molecules are to be distributed among the minerals with fixed molecules, whose quantity, however, is undetermined, by assigning to each mineral its proper oxide molecules in the proportions in which they occur in the ideal mineral molecule, as, for example; for orthoclase, $1K_2O.1Al_2O_3.6SiO_2$, and further, by indicating the number of molecules of each mineral by an algebraic symbol or letter. Thus, if there are x molecules of orthoclase, there must be assigned to them $xK_2O.xAl_2O_3.6xSiO_2$. The sum of all these assigned oxide molecules must equal the total amount of a particular chemical component in the rock after deducting that belonging to the minerals whose composition and quantity have been determined.

If there are more variable quantities than equations, that is, in general, more kinds of minerals than chemical components, it is necessary to reduce the number of unknown quantities by fixing the relative amounts of several minerals, or by stating their actual amounts.

THE CALCULATION OF ALFERRIC MINERALS.

As pointed out in the discussion of the classification of igneous rocks on a basis of salic and femic minerals, the reasons for omitting the alferric minerals are their variable and complex composition, our inadequate knowledge of the chemical character of the amphiboles and micas, and the inconstancy of their crystallization from magmas of any given chemical composition.

The questions naturally arise, How may these minerals be introduced into the calculation of the mineral composition of rocks from rock analyses? And what modifications of the norm would follow their introduction?

These questions, though not important for the classification of rocks according to the system here proposed, are of interest because of their relation to the general problem of chemico-mineralogical classification and the possibilities of its assuming a more elaborate form than that given it by us. The discussion of them emphasizes the relations between the aluminous ferro-

magnesian minerals and the salic and femic minerals, and makes evident the effect of the crystallization of the alferric minerals in a given magma upon the proportions of the other minerals.

We shall consider the problem of converting portions of salic and femic minerals, already calculated from the analysis of a rock, into alferric minerals. The minerals in question are: aluminous pyroxenes, aluminous amphiboles, micas and garnets. Rarer minerals of this kind will not be considered. As to the chemical composition of these minerals, it is known that the amounts of alumina and ferric oxide in monoclinic pyroxenes, amphiboles, and micas vary considerably in different cases, so that no simple statement can be made regarding the ratios of alumina to other constituents in these minerals. Moreover, there is no fixed relation between the amount of aluminous ferromagnesian minerals actually crystallized in a rock and the chemical composition of its magma. However, a study of the chemical composition of these minerals, so far as they have been analyzed, shows that their composition bears some relation to that of the magma from which they crystallized. In order to present this relationship as clearly as possible, Tables XII, XIII, and XIV have been arranged, as already mentioned, giving the chemical analyses of aluminous pyroxenes, amphiboles, and micas, and those of the rocks from which they were separated. It is evident from these tables that there is need for much thorough chemical investigation of the rock-making pyroxenes, amphiboles, and micas before we shall be in a position to cope successfully with the problem before us. For the present we can explain the method of dealing with the known factors in the problem and indicate that which may be pursued in doubtful cases.

The solution of the problem involves the transfer of alumina from salic to femic molecules, the necessity of introducing it in proportions corresponding to the known composition of these minerals in each case, the consequent readjustment of molecules among the femic minerals, and the disarrangement and readjustment of molecules among the salic minerals.

The process appears at first sight complex, but only involves

simple algebra, and when applied to a concrete example is not very intricate. Its value consists in familiarizing the student or investigator with the interdependence of the various mineral molecules in an igneous rock, and with the ranges of variation possible within rocks of the same chemical composition.

The minerals in question being characterized by a variable content of alumina, it is of first importance to note the amount of alumina present in different cases and to consider what transfer of chemical elements from salic to femic molecules would be necessary in order to produce such aluminous ferromagnesian minerals without destroying the stoichiometric proportions in the remaining salic and femic minerals.

In the case of a rock in which the calculation of the standard mineral composition showed the presence of an excess of Al_2O_3 over that required to form salic minerals it is evident that Al_2O_3 may be introduced into the ferromagnesian minerals by transferring it from this extra Al_2O_3.

But in the great majority of rocks there is no excess of Al_2O_3 in the sense here employed, and the production of aluminous ferromagnesian minerals affects the standard feldspathic molecules, so that the transfer of Al_2O_3 necessitates the transfer of those chemical bases united with it in equal proportions, namely, calcium, sodium, and potassium.

Each of these elements may enter into the composition of the minerals to be developed, whose molecules are more complex than those of femic minerals. A study of the analyses of the minerals in question shows that sodium enters into aluminous amphiboles independently of the acmite-riebeckite molecule ($Na_2O . Fe_2O_3 . 4SiO_2$), and that potassium also does, but to so small an extent in most instances that the error of estimating all of the alkali molecules as Na_2O is negligible. Conversely, potassium enters largely into the micas, and the sodium present is so small that the alkali molecules in mica may be calculated as though wholly K_2O without notable error.

Several chemico-mineralogical relations appear to control the amount of alumina, lime, and alkalies that may be transferred

from salic to femic minerals to form alferric minerals. And since the transfer of Al_2O_3 involves the CaO, K_2O, and Na_2O to various degrees, it is convenient to compare the amount of Al_2O_3 to be transferred with the principal one of these components taking part in the aluminous ferromagnesian mineral. This component becomes a unit of comparison for the other constituents of the particular mineral. In the pyroxenes and amphiboles CaO is the component next to Al_2O_3 most involved in the change. It becomes the unit of comparison in these minerals. In the micas K_2O plays this rôle.

The molecular relations which must be taken into account are expressed by ratios in the Tables XII, XIII, XIV at the end of this Part, and may be summed up as follows:

Aluminous pyroxenes (*Table XII*).—1. The ratio of Al_2O_3 to CaO ranges from almost nothing to 0.23. From these data the maximum limit is

$$\frac{Al_2O_3}{CaO} = 0.23 .$$

2. The nearly equal proportions between Fe_2O_3 and Na_2O indicate that the soda is present in the acmite molecule.

3. The generally small ratio between Na_2O and CaO. The ratio $\frac{Na_2O}{CaO}$ is less than 0.1 in most cases. Moreover, the presence of a notable amount of acmite molecule is indicated by the optical properties of the pyroxene.

4. The nearly constant ratio between MgO+FeO and CaO, which is approximately

$$\frac{MgO + FeO}{CaO} = 1 .$$

5. The $SiO_2 + TiO_2$ is approximately equal to the number of molecules of $MgO + FeO + CaO + 4Na_2O$, corresponding to pyroxene molecules $(MgFe)O . CaO . 2SiO_2$ and $Na_2O . Fe_2O_3 . 4SiO_2$ and $(Mg, Fe)O. (Al, Fe)_2O_3 \cdot SiO_2$.

Aluminous amphiboles (*Table XIII*).—The relations are less definite. There is a wide range in chemical composition, and it

will be necessary to consider special kinds of amphibole in different cases.

a). 1. For *hornblende* occurring in rocks with lime-soda-feldspar the ratio of Na_2O to CaO ranges from 0.08 to 0.21, while for hornblende in one alkali feldspathic rock it is 0.28, and for somewhat similar amphiboles, barkevikite and hastingsite, it reaches 0.35 and 0.43.

2. The ratio of Al_2O_3 to CaO ranges from 0.32 to 0.67 in the first mentioned cases, common hornblende, and from 0.44 to 0.85 in the second.

3. The ratio of MgO + FeO to CaO ranges from 1.73 to 2.72, being nearly 2.2 in most cases. It is not 3, as given in the textbooks generally.

4. It is to be noted that in hornblende in the more calcic rocks the ratio of MgO to FeO is 2 or more (from 2 to 4), while in those in the perfelic, alkalic rocks, this ratio is less than 1 (from 0.1 to 0.6). In other words, magnesia dominates ferrous iron in amphiboles of the first kind, while ferrous iron largely preponderates in those of the second kind,

5. The $SiO_2 + TiO_2$ is equal to the MgO + FeO + CaO plus an amount sometimes equal to $4Na_2O$, but not always.

6. The ratio of Fe_2O_3 to CaO is quite variable.

b) For *soda-amphiboles* of various kinds, excepting that occurring in comendite.

1. The ratio of Na_2O to CaO ranges from 1.23 to 4.6. That is, the lime is considerably less than the soda.

2. The ratio of Al_2O_3 to CaO ranges from 0.23 to 1.3.

3. The ratio of MgO + FeO to CaO ranges from 4.6 to 21.6, and the FeO is greatly in excess of MgO.

4. The variation in the SiO_2 indicates that Na_2O is partly present in the riebeckite molecule, and partly replaces CaO and (Mg, Fe)O in the RO . SiO_2 molecule.

Micas (*Table XIV*).—For these, as already said, the chemical component associated with Al_2O_3 which may be transferred from the feldspathic minerals is K_2O, and for purposes of calculation

it is convenient to compare other components with K_2O. The micas included in Table XIV are of three kinds—biotite proper, lepidomelane, and phlogopite.

a) For *biotite:*

Al_2O_3 ranges from 1.3 to 1.9, and the ratio of Fe_2O_3 to K_2O is 0.28 to 0.33, that is, nearly constant.

The ratio of $MgO + FeO$ to K_2O is 4.5 to 5.9 and magnesia is in excess of ferrous iron. The ratio of MgO to FeO is 1.1 to to 1.6. Average, 1.5.

The SiO_2 nearly conforms to the theoretical molecule $(K, H)_2O . (Al, Fe)_2O_3\ 2SiO_2 + n\ 2(Mg, Fe)O . SiO_2$.

b) For *lepidomelane:*

The ratio of Al_2O_3 to K_2O is nearly the same as in biotite, but that of Fe_2O_3 to K_2O is higher in two cases.

(Mg, Fe)O is lower, and ferrous iron dominates over magnesia.

c) For *phlogopite:*

The ratio of Al_2O_3 to K_2O is nearly the same as for biotite and lepidomelane, but that of Fe_2O_3 to K_2O is lower.

The ratio of $MgO + FeO$ to K_2O is nearly the same as in biotite, but magnesia greatly predominates over ferrous iron.

The ratio of SiO_2 to K_2O, although nearly the same as in biotite, does not conform to the formula given for biotite.

From these relations we may deduce the following method of transferring aluminous molecules from salic and non-aluminous molecules from femic to form molecules of augite, amphibole, and mica.

For the calculation of aluminous pyroxene: The kind of pyroxene to be calculated should depend upon the kind of rock in which it occurs.

a) If the femic minerals already calculated for the rock include acmite molecules, sufficient Na_2O and equal Fe_2O_3 are to be combined with diopside molecules to satisfy the ratio

$$\frac{Na_2O}{CaO} = D$$

(D standing for datum, the value given in the pyroxene or other mineral to be calculated); CaO in the ratio being equal to

CaO_d, in diopside, plus CaO_{an}, derived from anorthite, in consequence of the transfer of Al_2O_3 insufficient amount to satisfy the ratio

$$\frac{Al_2O_3}{CaO_d + CaO_{an}} = D .$$

Moreover, the ratio

$$\frac{(Mg,Fe)O}{CaO_d + CaO_{an}} = D ,$$

approximately 1, must be maintained by transferring (Mg,Fe)O from femic hypersthene or olivine. If the amount of these mineral is comparatively small a limit is set to the amount of aluminous pyroxene that can be produced.

b) If there are no acmite molecules estimated among the femic minerals, sufficient Na_2O must be transferred from soda-feldspathic molecules to satisfy the ratio

$$\frac{Na_2O}{CaO_d \pm CaO_{an}} = D ,$$

where $\pm\, CaO_{an}$ is the lime transferred from, or to, anorthite. If transferred from anorthite to diopside the sign is $+$, if to anorthite from diopside the sign is $-$.

This follows from the fact that the transfer of Na_2O from soda-feldspathic molecules liberates equal molecules of Al_2O_3, and if all of these are not needed to satisfy the ratio

$$\frac{Al_2O_3}{CaO_d \pm CaO_{an}} = D ,$$

as is the case in a number of pyroxenes given in Table XII, the Al_2O_3 not required withdraws CaO from diopside molecules to maintain the stoichiometric proportions obtaining in the salic minerals by making additional anorthite.

Fe_2O_3 is to be transferred from extra Fe_2O_3 (hematite) or from $FeO \,.\, Fe_2O_3$ (magnetite) in sufficient amount to satisfy the ratio.

$$\frac{Fe_2O_3}{CaO_d \pm CaO_{an}} = D .$$

The liberated FeO is to be added to sufficient (Mg, FeO) from hypersthene or olivine to maintain the ratio

$$\frac{(Mg,Fe)O}{CaO_d \pm CaO_{an}} = D \ .$$

When the sign of CaO_{an} is — the transfer of (Mg,Fe)O and the liberated FeO is to hypersthene or olivine from diopside.

A readjustment of SiO_2 is necessary according as (Mg,Fe)O is transferred from or to hypersthene or olivine, and as Na_2O is transferred from albite or nephelite. If there is extra SiO_2 it is placed first with the bases having strongest affinity for it unless these are already satisfied, when it appears as quartz.

In case the transfer is to be made to the complete exhaustion of one of the limiting components, the algebraic formulæ which can be devised for a particular case can be solved, but it frequently happens that augite occurs in rocks together with hypersthene or olivine, lime-soda-feldspars, and magnetite. The algebraic problem is indeterminable, since there are more unknown quantities than equations to satisfy them, unless the quantity of one or more of the minerals mentioned be given. More or less aluminous pyroxene within the limits of the magma appears to develop in different instances. The factors controlling the amount of augite crystallized in such cases are not at present known. The same statement may be made with reference to other aluminous ferromagnesian minerals.

For the calculation of aluminous amphiboles: a) *Hornblendes* contain more Al_2O_3 than Na_2O, and in the great majority of cases occur in rocks not having acmite molecules among the femic minerals.

To transform diopside molecules into those of hornblende sufficient Na_2O must be transferred from soda-feldspars, and enough CaO from anorthite with their equivalent Al_2O_3 to satisfy the ratios

$$\frac{Na_2O}{CaO_d + CaO_{an}} = D \quad \text{and} \quad \frac{Al_2O_3}{CaO_d + CaO_{an}} = D \ .$$

Furthermore

$$\frac{Fe_2O_3}{CaO_d + CaO_{an}} = D$$

must be satisfied by transferring Fe_2O_3 from Fe_2O_3 (hematite), or from $FeO.Fe_2O_3$ (magnetite).

The liberated FeO with (Mg,Fe)O from hypersthene or olivine must be transferred to satisfy the ratio

$$\frac{(Mg,Fe)O}{CaO_d + CaO_{an}} = D .$$

SiO_2 must be adjusted in the manner already indicated for the case of pyroxene.

b) The calculation of the more alkalic amphiboles which occur in rocks rich in soda and iron and comparatively poor in lime and magnesia is to be made in the following manner :

Sufficient acmite molecules are transferred to satisfy the ratio

$$\frac{Fe_2O_3}{CaO_d \pm CaO_{an}} = D .$$

Equal Na_2O from acmite plus sufficient Na_2O from soda feldspars is transferred to satisfy the ratio

$$\frac{Na_2O}{CaO_d \pm CaO_{an}} = D .$$

Al_2O_3 equal to Na_2O transferred from soda-feldspars is liberated and enough of it is transferred to amphibole to satisfy the ratio

$$\frac{Al_2O_3}{CaO_d \pm CaO_{an}} = D .$$

If all the liberated Al_2O_3 is not required to satisfy the last named ratio, CaO must be withdrawn from diopside to form additional anorthite, and the sign of CaO_{an} is minus.

If more Al_2O_3 than that liberated from soda feldspars is needed to satisfy the ratio in question additional Al_2O_3 with CaO is transferred from anorthite, and the sign of CaO in the expression is plus.

The ratio

$$\frac{(Mg,Fe)O}{CaO_d \pm CaO_{an}} = D$$

must be established as well as that of

$$\frac{MgO}{FeO} = D$$

since the latter is highly characteristic.

The adjustment of SiO_2 follows the ratio

$$\frac{SiO_2}{CaO_d \pm CaO_{an}} = D$$

and the requirements of the other molecules.

For the calculation of ferromagnesian mica.—The process is essentially the same for various kinds, the values of the ratios varying for biotite, lepidomelane, and phlogopite.

In most cases Al_2O_3 is in excess of K_2O, and in transferring K_2O from feldspathic molecules the accompanying equal Al_2O_3 is not sufficient to satisfy the ratio

$$\frac{Al_2O_3}{K_2O} = D\ .$$

Extra Al_2O_3 may be derived from corundum when estimated present, and this will be the case in numerous rocks in which muscovite and biotite have developed.

If there is no extra Al_2O_3 of this kind, Al_2O_3 must be transferred from anorthite until the ratio in question is satisfied. The liberated CaO must be transferred to diopside molecules.

Fe_2O_3 is to be transferred from Fe_2O_3 (hematite) or FeO. Fe_2O_3 (magnetite), and the liberated FeO is to be added to (Mg,Fe)O, to satisfy the ratio

$$\frac{Fe_2O_3}{K_2O} = D\ .$$

(MgFe)O must be transferred from hypersthene or olivine to satisfy the ratio

$$\frac{(Mg,Fe)O}{K_2O} = D\ ,$$

and the ratio $\frac{MgO}{FeO}$ must be maintained according to the kind of mica.

SiO_2 and TiO_2 are to be transferred according to their respective ratios

$$\frac{SiO_2}{K_2O} = D \quad \text{and} \quad \frac{TiO_2}{K_2O} = D\ .$$

After which SiO_2 must be adjusted among the molecules affected. In general some SiO_2 will be liberated and the amount of quartz in quartz-bearing rocks will be increased. In other cases lower silicates will be raised.

The calculation of muscovite is simple, for the reason that it occurs mainly in rocks in which there is an excess of Al_2O_3, estimated as corundum.

Since in common muscovite $H = 2K$ the following ratios obtain:

$$\frac{H_2O}{K_2O} = 2\ , \quad \frac{Al_2O_3}{K_2O} = 3\ , \quad \frac{SiO_2}{K_2O} = 6\ .$$

Such a muscovite equals orthoclase plus corundum plus water.

$$2H_2O + K_2O + 3Al_2O_3 + 6SiO_2 = K_2O + Al_2O_3 + 6SiO_2 + 2Al_2O_3 + 2H_2O\ .$$

Hence to the molecules of hypothetical corundum add half as many of the orthoclase and an equal number of H_2O. The distribution of SiO_2 remains as before, the amount of quartz has not been affected.

From the foregoing it is seen that the development of augite in rocks reduces the amount of anorthite molecules calculated among the salic minerals and also reduces the amount of hypersthene or olivine that appear as femic. It affects the distribution of silica by liberating a part of that allotted to anorthite when the (Mg,Fe)O is derived from hypersthene, or when Na_2O is transferred from albite molecules. Its development would reduce the amount of olivine rather than hypersthene when both are otherwise normatively present.

The crystallization of hornblende reduces the amount of anorthite and hypersthene or olivine reckoned as standard min-

erals at a greater rate than that of augite would, in proportion to the amount of femic diopside molecules converted into hornblende, because the ratio of Al_2O_3 to CaO is higher, and the ratio of (Mg,Fe)O to CaO is twice as great as in augite. The effect on the SiO_2 would be similar.

The reduction of anorthite molecules by both these processes would affect the character of the plagioclase actually developed in the rock as compared with that reckoned as standard.

The development of mica would reduce the molecules of potash feldspar or of leucite, and the formation of biotite would also reduce the amount of hypersthene or olivine, and that of magnetite. It would reduce the amount of calculated corundum, or, in the absence of this extra Al_2O_3, would reduce the molecules of anorthite and increase those of diopside or wollastonite. The distribution of SiO_2 would be affected, and in cases where there is no extra Al_2O_3 and where (Mg,Fe)O is derived from hypersthene SiO_2 would be liberated to raise lower to higher silicates, or to form quartz.

Garnet.— In the matter of garnet it is easily seen that to form simple lime-alumina garnet (grossularite), $3CaO.Al_2O_3.3SiO_2$, it is necessary to combine anorthite molecules with femic wollastonite, $CaO.SiO_2$, with the liberation of silica. And it will be found that this garnet is frequently developed in rocks whose estimated standard minerals include wollastonite, and its crystallization reduces the amount of anorthite.

AN EXAMPLE OF CALCULATION.

As an illustration of the several processes above described we present the case of the Butte granite, because of its fairly uniform composition as shown by five analyses,[1] its distinct crystallization, which is of such size as to permit of accurate microscopical measurement, and because the two aluminous ferromagnesian minerals, biotite and hornblende, have been separated and analyzed. The rock from which these minerals

[1] WEED, W. H., JOUR. GEOL., p. 739, 1899.

were separated has been analyzed, and this analysis forms the basis for the calculation of the standard mineral composition. It is from Walkerville Station, near Butte, Mont. The thin section measured is from a specimen of very fresh rock taken near the surface twenty feet from the outcrop of the Parrot vein at Butte.

TABLE VII.

		Mol.	Pyr.	Ilm.	Ap.	Mag.	Orth.	Alb.	An.	Diop.	Hyp.	Qu'tz.
SiO_2	63.88	1.065	..	..	..	..	270	270	130	6	64	323
Al_2O_3 ...	15.84	.155	..	..	..	..	45	45	65	..	..	..
Fe_2O_3 ...	2.11	.013	..	..	..	13	..	..	..		..	..
FeO	2.59	.036	2	8	..	13	..	..	..	3	63	..
MgO	2.13	.053	..	..	..	..	..	..	..		..	..
CaO	3.97	.071	..	..	3	..	..	..	65	3	..	..
Na_2O	2.81	.045	..	..	..	..	..	45	..	..	..	..
K_2O	4.23	.045	..	..	..	..	45	..	..	..	..	..
H_2O+ ...	.66	....	..	..	..	..	..	..	..	..	..	..
H_2O- ...	.22	....	..	..	..	..	..	..	..	..	..	..
TiO_2	.65	.008	..	8	..	..	..	..	..	..	..	..
P_2O_5	.21	.001	..	..	1	..	..	..	..	..	..	..
MnO	.07	.001	..	..	..	..	..	..	..	..	1	..
SrO	.02	.000	..	..	..	..	..	..	..	..	..	..
BaO	.09	.000	..	..	..	..	..	..	..	..	..	..
Li_2O	tr	....	..	..	..	..	..	..	..	..	..	..
SO_3	.34	.004	4	..	..	..	..	..	..	..	..	..
Cl	tr	....	..	..	..	..	..	..	..	..	..	..
	99.82											

FORMULA.	MOL. WT.		NORM.		
SiO_2	323 × 60	quartz	19.38	Q	19.38
$K_2O . Al_2O_3 . 6SiO_2$	45 × 556	orthoclase	25.02	F	66.67
$Na_2O . Al_2O_3 . 6SiO_2$	45 × 524	albite	23.58		
$CaO . Al_2O_3 . 2SiO_2$	65 × 278	anorthite	18.07		
$CaO . SiO_2$	3 × 116	diopside	.67	P	7.45
$MgO . SiO_2$	2 × 100				
$FeO . SiO_2$	1 × 132				
$MgO . SiO_2$	51 × 100	hypersthene	6.78		
$FeO . SiO_2$	13 × 132				
$FeO . Fe_2O_3$	13 × 232	magnetite	3.01	M	4.24
$FeO . TiO_2$	8 × 152	ilmenite	1.22		
FeS_2	2 × 120	pyrite	.24	A	.55
$3CaO . P_2O_5$	1 × 310	apatite	.31		
		etc.	.99		
			99.27		

a) *The calculation of the standard minerals, or norm*, is expressed in Table VII. MnO is combined with FeO making 0.037 molecules. SO_3 is allotted to FeO to form FeS_2 becauseof the pyrite known to be present in the rock, TiO_2 to ilmenite, P_2O_5 to apatite, Fe_2O_3 to magnetite, K_2O to orthoclase, Na_2O to albite, the remaining Al_2O_3 (0. 065 mol.) to anorthite, the remaining

CaO to diopside, the remaining (Mg,Fe)O to hypersthene, and the remaining SiO_2 to quartz. From the respective molecules the percentage weights are found by multiplying each by the molecular weight.

The classification of this rock from the data given in Table VII has been described on a previous page as an example of an intermediate rock.

b) *To calculate the mode* from the chemical analysis of the rock we have to introduce biotite and hornblende into the calculation, and we have the chemical analysis of each given in Tables XIII and XIV. We will assume that they contain all the magnesia (MgO) and all the iron oxide (FeO and Fe_2O_3), except that which goes into pyrite, magnetite and ilmenite. For these are the only ferromagnesian minerals observed in thin sections of the rock except a small amount of pyroxene intergrown with the hornblende. This was probably included in the hornblende material analyzed so that the analysis represents the mixture and may for the present calculation be treated as the composition of one mineral.

In Tables XIII and XIV are found the following ratios:

For *Butte hornblende:*

$$\frac{MgO}{CaO} = 1.53\,, \quad \frac{FeO}{CaO} = .71\,, \quad \frac{Al_2O_3}{CaO} = .32\,, \quad \frac{Fe_2O_3}{CaO} = .15\,,$$

$$\frac{Na_2O}{CaO} = .12\,, \quad \frac{SiO_2}{CaO} = 3.79\,.$$

For *Butte biotite:*

$$\frac{MgO}{K_2O} = 3.12\,, \quad \frac{FeO}{K_2O} = 1.96\,, \quad \frac{Al_2O_3}{K_2O} = 1.3\,, \quad \frac{Fe_2O_3}{K_2O} = .32\,,$$

$$\frac{H_2O}{K_2O} = .7\,, \quad \frac{SiO_2}{K_2O} = .6\,, \quad \frac{TiO_2}{K_2O} = .44\,.$$

If x=molecules of CaO in hornblende, y=molecules of K_2O in biotite, z=molecules of Fe_2O_3 in resulting magnetite, w= molecules of TiO_2 in resulting ilmenite,

Then $2.24x+5.08y+z+w=88$ =(Total (Mg,Fe)O less FeO in pyrite).

$$.15x+\ .32y+z \quad =13=(\text{Total } Fe_2O_3).$$

$$.44y+w \quad =\ 8=(\text{Total } TiO_2).$$

$$.32x+1.3\,y \quad =12x+y+(x-3)=(\text{transferred } Al_2O_3).$$

That is, the Al_2O_3 in hornblende and biotite equals the transferred soda, potash and transferred lime, which latter equals the CaO in hornblende less that previously allotted to dioside $(x-3)$. From these equations are derived the following values:

$$x = 8.4\ (8)\,,\quad y = 12.4\ (12)\,,\quad z = 7.8\ (8)\,,\quad w = 2.5\ (3)\,.$$

From these values of x, y, z and w the readjustments for all the minerals are made as indicated in Table VIII.

TABLE VIII.

	Mol.	Pyr.	Ilm.	Mag.	Ap.	Orth.	Alb.	An.	Biot.	Horn.	Quartz.
SiO_2	1.065	.	.	.	.	198	264	120	72	30	381
Al_2O_3 ...	.155	.	.	.	.	33	44	60	16	2	...
Fe_2O_3 ...	.013	.	.	8	.	...	...	...	4	1	...
FeO	.036	2	3	8	.	...	...	...	19	4	...
MgO	.053	.	.	.	.	...	...	...	41	12	...
CaO	.071	.	.	.	3	...	...	60	..	8	...
Na_2O	.045	.	.	.	.	...	44	...	..	1	...
K_2O	.045	.	.	.	.	33	...	...	12	..	...
H_2O+ ...	.....	.	.	.	.	...	...	...	8	..	...
H_2O- ...	.....	.	.	.	.	...	...	...	..	..	...
TiO_2	.008	.	3	.	.	...	...	...	5	..	...
P_2O_5	.001	.	.	.	1	...	...	...	..	..	...
MnO	.001	.	.	.	.	...	...	...	..	1	...
SO_3	.004	4	.	.	.	...	...	...	..	..	...
Etc......	.....	.	.	.	.	...	...	...	...	...	...

$x = 8 =$ mol. CaO in hornblende.
$y = 12 =$ mol. K_2O in biotite.
$z = 8 =$ mol. Fe_2O_3 in magnetite.
$w = 3 =$ mol. TiO_2 in ilmenite.

FORMULA.	MOL. WT.		MODE.
SiO_2	381×60	= quartz	22.86
$K_2O.Al_2O_3.6SiO_2$	33×556	= orthoclase	18.35
$Na_2O.Al_2O_3.6SiO_2$	44×524	= albite	23.06
$CaO.Al_2O_3.2SiO_2$	60×278	= anorthite	16.68
$8H_2O$	8×18		
$12K_2O$	12×94		
$16Al_2O_3$	16×102		
$4Fe_2O_3$	4×160	= biotite	10.92
$41MgO$	41×40		
$19FeO$	19×72		
$5TiO_2$	5×80		
$72SiO_2$	72×60		
$1Na_2O$	1×62		
$8CaO$	8×56		
$12MgO$	12×40		
$5FeO$	5×72	= hornblende =	3.56
$2Al_2O_3$	2×102		
$1FeO_3$	1×160		
$30SiO_2$	30×60		
$FeO.Fe_2O_3$	8×232	= magnetite =	1.86
$FeO.TiO_2$	3×152	= ilmenite =	.46
FeS_2	2×120	= pyrite =	.24
$3CaO.P_2O_5$	1×310	= apatite =	.31
		etc.	.85
			99.15

c) *The process of calculating the norm from the mode*, that is, the standard mineral composition from a microscopical investigation of rock sections, may be illustrated as follows :

Two thin sections of Butte granite were examined ; one from a surface excavation, twenty feet from the Parrott vein, very fresh, with almost no signs of alteration, the other from similar rock used in building in the city of Butte, the location of the quarry not noted.

In the first section an aggregate distance of 12,740 units of the micrometer scale was measured, embracing 604 measurements. The average diameter of the plagioclase crystals was 32 units, and the total length of plagioclase diameters was 5,492. Table IX shows the lengths, relative volumes, assumed specific gravities of each mineral, and the resulting percentages by weight.

TABLE IX.

	First Rock.				Second Rock.	
	Total Diameters.	Relative Volumes.	Sp. gr.	Weights.	Relative Volumes.	Weights.
Quartz	2,954	23.17	2.65	22.55	20.97	20.34
Orthoclase	2,373	18.62	2.57	17.57	21.07	19.82
Plagioclase	5,492	43.10	2.68	42.47	42.29	41.48
Biotite	1,130	8.87	3.00	9.77	8.15	8.94
Hornblende	482	3.78	3.20	4.44	4.84	5.67
Pyroxene	252	1.97	3.30	2.37	2.07	2.50
Magnetite	51	.40	5.17	.76	.54	1.02
Pyrite	6	.04	5.00	.07	.02	.04
	12,740	99.95		99.98	99.95	99.81

In the second rock section examined an aggregate distance of 7,122 units of the scale was measured, embracing 403 measurements. The average diameter of the plagioclase was 24 units, and the total length of plagioclase diameters was 3,012. The relative volumes and weights are given in the last two columns of the Table.

A comparison of the two cases shows how closely the rocks resemble one another, the second being slightly higher in orthoclase and lower in quartz than the first. Other sections from

Butte granite from other localities in the vicinity of Butte show slightly more ferromagnesian minerals. Weed[1] has called attention to the generally uniform composition of this great body of granite as indicated by five chemical analyses, one of which is given in the tables of mica and hornblende. The specimen from near the Parrot vein will be made the basis of the following discussion.

Optical investigation of the plagioclase by the Michel-Lévy method with Carlsbad twins of albite twins showed that the central portion of each crystal has approximately the composition of Ab_1An_1, but the marginal zones are more sodic, having in some crystals the composition of oligoclase as indicated by the optical orientation and the relative index of refraction as compared with quartz by the Becke method. Without making the necessary observations for estimating the relative proportions of the several zones, and the average composition of the plagioclase as a whole, it was seen that the greater part of each crystal is about $Ab_1 An_1$, and only a narrow margin is oligoclase, but the optical orientation of the outer portions shifts gradually in most cases from the central part to the margin. The average composition of the plagioclase is probably andesine somewhat more sodic than $Ab_1 An_1$. If Ab_3An_2, it would have the composition of the mixture of albite and anorthite calculated from the chemical analysis of the Butte granite from Walkerville Station already cited, after developing biotite and hornblende. In this case the 42.47 per cent. of plagioclase would yield by molecular calculation 24.71 per cent. albite and 17.76 per cent. anorthite. In the second rock there would be 24.29 per cent. albite and 17.18 per cent. anorthite. The orthoclase may be considered as wholly potassic and reckoned as pure orthoclase.

In order to obtain the salic and femic components of the biotite, hornblende, and pyroxene, since the other minerals are standard, we may take the analysis of Butte biotite from Table XIV and multiply it by 0.0977, the percentage weight of biotite, and take the analysis of Butte hornblende from Table XIII and multiply it by 0.0681, the combined percentage weight of hornblende and

[1] WEED, W. H., JOUR. GEOL., Vol. VII, pp. 737–50.

pyroxene, for the reason already given. The resulting constituents reduced to molecular proportions may be distributed among salic and femic minerals as shown in the accompanying Table X.

From these data we deduce the standard mineral composition of the rock from near the Parrot vein as follows:

TABLE X.

	9.77 % Biot.	6.81% Hornbl.	Sum.	Fluor.	Ilm.	Mag.	Orth.	Alb.	An.	Diop.	Hyp.	Minus Qu'rtz
SiO_2	3.58	3.11	.111	..	..	..	66	6	12	12	64	−49
Al_2O_3	1.37	.46	.018	..	..	..	11	1	6	..	..	....
Fe_2O_3	.52	.34	.005	..	..	5	..	..	..	..	..	....
FeO	1.37	.71	.029	..	6	5	..	..	..	2	16	....
MgO	1.21	.82	.051	..	..	..	..	..	..	4	47	....
CaO	.00	.76	.014	2	..	..	..	..	6	6	..	....
Na_2O	.01	.05	.001	..	..	..	..	1	..	..	..	....
K_2O	.91	.08	.011	..	..	..	11	..	..	..	..	....
H_2O-	.12	.03	....	..	..	..	..	..	..	..	..	....
H_2O+	.36	.16	....	..	..	..	..	..	..	..	..	....
TiO_2	.35	.10	.006	..	6	..	..	..	..	..	..	....
P_2O_5	.01	.02	.000	..	..	..	..	..	..	..	..	....
MnO	.02	.04	.001	..	..	..	..	..	..	..	1	....
BaO	.01	....	....	..	..	..	..	..	..	..	..	....
Cl	.02	....	....	..	..	..	..	..	..	..	..	....
F	.07	.02	.004	4	..	..	..	..	..	..	..	....

FORMULA.	MOL. WT.		
SiO_2	49 × 60	= quartz =	2.94
$K_2O.Al_2O_3.6SiO_2$	11 × 556	= orthoclase =	6.12
$Na_2O.Al_2O_3.6SiO_2$	1 × 524	= albite =	.52
$CaO.Al_2O_3.2SiO_2$	6 × 278	= anorthite =	1.67
$CaO.SiO_2$	6 × 116	= diopside =	1.36
$MgO.SiO_2$	4 × 100		
$FeO.SiO_2$	2 × 132		
$MgO.SiO_2$	47 × 100	= hypersthene =	6.94
$FeO.SiO_2$	17 × 132		
$FeO.Fe_2O_3$	5 × 232	= magnetite =	1.16
$FeO.TiO_2$	6 × 152	= ilmenite =	.91
CaF_2	2 × 94	= fluorite =	.19

Percentages Determined from Rock.		Readjustments.		Standard Mineral Composition.	
Quartz	22.55		−2.94	Quartz	19.61
Orthoclase	17.57		+6.12	Orthoclase	23.69
Plagioclase	42.47	Albite 24.71	+ .52	Albite	25.23
		Anorthite 17.76	+1.67	Anorthite	19.43
Biotite	9.77	Diopside	1.36	Diopside	1.36
Hornblende	4.44	Hypersthene	6.94	Hypersthene	6.94
Pyroxene	2.37	Fluorite	.19	Fluorite	.19
		Ilmenite	.91	Ilmenite	.91
Magnetite	.76		+1.16	Magnetite	1.92
Pyrite	.07			Pyrite	.07
					99.35

The approximate chemical composition of this rock is found by separating each of the minerals observed in the rock into its chemical components. The results are given below:

TABLE XI.

	Biotite.	Hornblende and Pyroxene.	Magnetite.	Pyrite.	Anorthite.	Albite.	Orthoclase.	Quartz.	First Rock.	Second Rock.	Atlantic Mine.
SiO_2	3.58	3.11	...	...	7.66	16.97	11.37	22.55	65.24	64.43	64.34
Al_2O_3	1.37	.46	...	...	6.52	4.81	3.22	.....	16.38	16.46	15.72
Fe_2O_3	.52	.34	.52	...	....	.....	.....	.....	1.38	1.57	1.62
FeO	1.37	.71	.23	.04	....	.....	.....	.....	2.35	2.42	2.94
MgO	1.21	.82	...	...	....	.....	.....	.....	1.93	2.10	2.17
CaO	.00	.76	...	...	3.57	.....	.....	.....	4.33	4.38	4.24
Na_2O	.01	.05	...	...	....	2.93	.....	.....	2.99	2.95	2.76
K_2O	.91	.08	...	...	....	.....	2.97	.....	3.96	4.27	4.04
H_2O-	.12	.03	...	...	....	.....	.....	.....	.15	.15	.25
H_2O+	.36	.16	...	...	....	.....	.....	.....	.52	.43	.76
TiO_2	.35	.10	...	...	....	.....	.....	.....	.45	.35	.53
P_2O_5	.01	.02	...	...	....	.....	.....	.....	.03	.04	.14
MnO	.02	.04	...	...	....	.....	.....	.....	.06	.06	.12
SrO	...	....	...	...	....	.....	.....	.....	...	...	.03
BaO	.01	....	...	...	....	.....	.....	.....	.01	.01	.06
Cl	.02	....	...	...	....	.....	.....	.....	.02	.02	.03[1]
F	.07	.02	...	...	....	.....	.....	.....	.09	.09	.005[2]
S	....	....	...	.04	....	.....	.....	.....	.04	.02	.03[3]
....	....	....	...	...	....	.....	.....	.....	.....	.....	.02[4]
									99.93	99.75	99.805

[1] CO_2 [2] Cu [3] FeS_2 [4] ZrO_2

The chemical composition of the second rock from Butte in which the minerals were measured is given in the same table, and also the analysis of Butte granite from the Atlantic Mine. The similarity of the results is an indication of the success of the process in this instance.

With the data here assembled it is possible to classify the rock from near the Parrot vein with almost as much accuracy as though it had been analyzed chemically. In other cases the data may not be so nearly correct, but the error in many cases will be quite within the limits of variation for the division of the classification to which the rock belongs.

It is evident that there is need for more chemical work upon the component minerals of igneous rocks and the correla-

tion of their optical properties and chemical composition with that of the rocks containing them. The necessity is also apparent for complete analyses not only as to the main constituents, but also as regards some of the constituents hitherto considered as rare or of little importance, but which modern investigation has shown to be widely distributed and often of considerable influence on the norm and mode. The constituents present usually in small amounts are distributed very unequally among the various kinds of rock magmas, and it would save the careful analyst much needless labor if the petrographer would indicate to him those which it is advisable to look for and determine.

EPILOGUE.

Some who read this essay will, without doubt, object to the method of classification herein proposed because it is new and embodies new principles, since experience has shown that one's mental attitude toward new methods is on the whole conservative, and tends to resist their introduction. It is, also, easier to travel along a familiar and oft-trodden path, no matter how crooked and obstructed it may be, than to hew out a new one and provide a broader way for the future.

Objection will doubtless be made that the system, on account of the definite quantitative character of its divisions, throws a greater amount of mental responsibility in classifying upon the one who uses it. Thus, for instance, at the very outset, it will often happen that megascopically a rock will be so close to one of the lines separating two different classes that it will be difficult to know to which one it should be assigned. And it will sometimes happen that later chemical or microscopical investigation will show the preliminary classification to have been wrongly made. Moreover, when such examinations have been made, it will often occur that it is largely a matter of judgment as to which of two adjacent Orders, Rangs, or Grads a rock properly belongs.

To some this mental responsibility is distasteful and unsatisfactory; they desire a classification made up of a number of simple divisions like neat pigeon-holes or compartments into

which each object can be easily and promptly thrust and docketed, and any method which fails to achieve this and relieve them of considerable mental effort in classifying rocks will not, in their estimation, be a proper one.

Unfortunately the difficulty in this respect lies not in the method, but is inherent in the subject itself. Rocks grade into one another in all directions, chemically, minerally, and texturally, and these again overlap in the different modes of geological occurrence.

Therefore, unless the future should reveal new properties of rocks, as yet unknown and unsuspected, which may be used as bases of classification, every method so far devised, or which can be devised, must have artificial lines of division, and cause the petrographer trouble in certain cases in deciding where his rocks belong. The erection of the monzonite group by Brögger is a good example of this. Where rocks contained about equal amounts of orthoclase and plagioclase it was formerly difficult to say whether they should be classed as syenites or diorites. The formation of the monzonite group avoided this difficulty, but in its turn gave rise to two others whose sum total is greater than the original one; for it is clear that it will be equally difficult now to decide whether a syenite with considerable plagioclase is still a syenite or a monzonite, and the same difficulty is met in diorites with considerable orthoclase. Thus, the formation of new groups simply multiplies the difficulty; it does not remove it.

The system which we propose does not, therefore, meet this trouble; it does not pretend to, for any system based on our present knowledge of rocks which should claim this would be in the nature of a mere nostrum, and would simply profess to do what it could not perform. In the ultimate analysis, every system will and must throw on the petrographer the mental responsibility of deciding, in a considerable number of cases, where rocks lie close upon divisional lines, into which of two divisions they must be put. He may not like this, but it cannot be avoided.

In different systems this difficulty is met in greater or lesser degree in different parts of the systems. In the one we propose it occurs chiefly in doubtful cases, at the beginning, and in the

sum total we believe that it is less, or at all events no greater, than in any system heretofore proposed. But in regard to this each must judge for himself.

Objection may also be raised to this method of classification, that it entails a greater amount of labor upon the petrographer than those now in use. Perhaps there are some who, recalling the possibility of glancing through a microscope and noticing the presence of striated feldpars, with one or more dark-colored minerals, and promptly identifying the rock, regret the introduction of the chemical character of the feldspars and the quantitative determination of all the minerals. But to such we have no apology to make. Already precise optical methods of determining the feldspars are in use; and the confusion resulting from an absence of the quantitative element in rock definitions is becoming intolerable. The time has come when the petrographer should demand the exactness and sharpness of definition which, though obtained only by patient and careful work, add clearness to the conceptions and proportionate weight to the results of petrographic investigation.

It may be thought that the method of obtaining the approximate chemical composition of the magma by optical study and computation of the minerals in a rock is tedious, as it might possibly take several hours of work. But let one who considers this seriously make a good, careful, and accurate chemical analysis and note the amount of time consumed. We urge him not to throw the task on someone else, especially not on some beginner in analytical chemistry, as has unfortunately so often happened, but to make the analysis himself. Indeed, every petrographer should have made enough analyses to properly appreciate what they mean, after which we feel sure he will not object to the length of time involved in a microscopical analysis when one is possible.

Again, we have assumed as a condition for proper and convenient classification that it should be dichotomous, since not more than two factors can be handled advantageously at one time. To those who may not agree with this proposition we can only recommend the trial of forming a classification, using three

or more factors at once. We have been through this phase of belief most thoroughly, and have convinced ourselves that two factors are all that can be handled at once without complications which would destroy the practical usefulness of any system. We believe that anyone who tries it will come to the same conclusion.

Furthermore, repeated trials have led us to think that a fivefold division is the most practicable one and the one best suited for the needs of petrography. We have applied this logically throughout, except in certain cases where a threefold seemed sufficient.

We desire also to ask the reader to bear in mind that the scheme of classification and nomenclature herein proposed is of much greater importance in some features than in others. The important points to bear in mind, and on which our system rests, are these:

a) The bringing together of rocks of *similar chemical composition* into the same divisions.

b) The resolution of a rock, either from its chemical or microscopical analysis, into quantitative amounts of certain *standard* minerals.

c) The establishment of a strictly *quantitative* basis of comparison of rock constituents, so that all constituents are valued according to their proportions.

d) The division of the minerals into two main groups, *salic* and *femic*, thus obtaining two factors, and the application of the fivefold division.

e) The recognition of the relation of the *mode* to the *norm.*

Time, use, and experience, if this system gains the currency we hope for it, may cause modifications in the smaller divisions; and the suggestions we have made in regard to nomenclature, both of rocks and of descriptive terms for their textures, may only in part be followed. But these are minor features and their importance is relatively small compared with the main points enumerated above. It is upon them that the system rests, and upon their adoption or rejection that it must either stand or fall.

The petrographer who believes that these fundamental points are correct and who is willing to accept them will not wish to reject the whole system because he may not agree with some of its minor features, but the one who does not accept the fundamental points will have no use for this system, or any of its features, great or small.

At first it will not be easy for the petrographer to think of rocks as expressed in this system ; it will require some use and experience. Nearly everywhere over the whole field it introduces new conceptions, and we firmly believe more correct and logical ones than have hitherto prevailed. We have made no attempt to modify, or patch up, or define the older previous systems, for we believe that the day for efforts of that kind has passed ; that they have had their use and should now be replaced by something more in accord with the results of the great amount of recent investigations, and of our present knowledge, and therefore better adapted to present and future needs. It is of course easier to patch and wear old garments than to make new ones, but to confess this fact as controlling one's attitude toward new propositions would be merely to acknowledge a condition of mental supineness.

If petrographers believe this system to be an advance over previous ones, we offer no apology for imposing a new mental burden upon them, for it is obvious that the ever-increasing accumulation of knowledge of the chemical and mineral properties of rocks, and of their relations to one another and to their texture, mode of occurrence, and their origin impose a greater task on modern petrographers than was borne by those of a former generation. And since it is not to be assumed that the present state of petrographical knowledge is complete, provision should be made for expansion and adjustment along lines which seem to be those in which future development will take place.

Whitman Cross,
Joseph P. Iddings,
Louis V. Pirsson,
Henry S. Washington.

	n	*o*	
	Pyrox.	Rock.	Pyrox
SiO_2 .	45.23	42.78	44.65
	.754		.74
Al_2O_3	7.73	8.66	6.62
	.075		.06
Fe_2O_3	2.95	....	5.02
	.018		.031
FeO .	4.07	17.96	3.87
	.056		.054
MgO	12.25	10.06	14.76
	.306		.369
CaO .	23.37	12.29	20.32
	.417		.363
Na_2O	.47	2.31	1.29
	.007		.021
K_2O .	.12	.62	.49
	.001		.005
H_2O+	.37	3.96	....
H_2O-	....	....	....
TiO_2 .	4.28	.28	2.93
	.053		.037
P_2O_5	none	....	....
SO_3 ..	....	....	....
Cl...	....	....	....
Cr_2O	....	....	....
NiO	.05	trace	....
MnO	.07	.95	....
	.001		
BaO.	none	....	....
SrO	none	....	....
Ce_2O			
Di_2O	....	....	....
	100.96	99.87	99.95
Sp. g	....	2.829	3.411
	....	....	....

a) *D* | *n*) *Augite* from *nephel*
Surv., p. 63.

b) *D* | *o*) *Augite* from *limburg*

p) *Augite* from *dolerite*

c) *D* | *Geol. Surv.*, p.

q) *Augite* from *monchiq*
234, 235.

d) *A* | *r*) *Augite* from *basalt* (

e) *A* | *s*) *Augite* (c: c=54°) fr
El. Gest., p. 346

f) *A* | *t*) *Aegirite* from *nephel*

g) *A* | Serra do Poços d

a) D Leucitophyre . . . .
b) D Analcite-basalt . .....
c) D Nephelinite .... . .
d) A Nephelite-basalt .... .
e) A Limburgite ....
f) A Dolerite ....
g) A Monchiquite ....
h) A Basalt ....
i) A Leucite-tephrite...... ....
j) A Eleolite-syenite . ....

TABLE XII. ANALYSES OF PYROXENES AND THE ROCKS CONTAINING THEM.

	a Rock.	a Pyrox.	b Rock.	b Pyrox.	c Rock.	c Pyrox.	d Rock.	d Pyrox.	e Pyrox.	
SiO_2	50.23	50.81 .848	58.08	50.33 .839	61.93	50.63 .844	42.30	52.57 .876	52.20 .870	.
Al_2O_3	11.22	none	19.50	.30 .003	13.18	.87 .008	12.63	1.33 .013	2.36 .022	
Fe_2O_3	3.34	1.19 .007	3.63	....	3.63	3.33 .020	15.48	5.86 .036	8.51 .053	....
FeO	1.84	1.82 .025	2.58	12.37 .172	2.31	8.39 .116	5.07	3.23 .044	none	....
MgO	7.09	17.42 .435	.79	10.98 .274	4.59	13.01 .325	5.24	12.36 .309	12.83 .321	....
CaO	5.99	23.32 .416	3.03	22.01 .393	3.48	21.30 3.80	8.42	18.49 .330	18.42 .329	....
Na_2O	1.37	.76 .012	5.73	2.14 .034	2.67	1.02 .016	5.19	3.80 .061	2.56 .041	....
K_2O	9.81	.42 .004	4.50	.94 .010	6.11	.50 .005	2.73	1.03 .011	.78 .008	....
H_2O+	1.72	.31	1.01	....	1.14	....	3.59	....	....	....
H_2O-	.03	..	..	....	....	....	....	....	....	....
TiO_2	2.27	3.03	1.00	.66 .008	....	.79 .010	....	2.18 .024	3.12 .039	....
P_2O_5	1.89		.54	....	....	....	.65	....	....	....
SO_3	.74	.		....	...	....	..	....	....	
Cl	.03			....	....	....	....	....	....	....
Cr_2O_3	.10	.	..		.	.		...	.	.
NiO				...			.	....	...	.
MnO	.05	.03		.	.		.12	.15 .002	.12 .001	
BaO	1.23	....	....	....	....	....	....	....	....	....
SrO	.24									SrO..
Ce_2O_3, Di_2O_3	.03	....	....	....	....	....	....	....	....	ZrO_2.
		99.16	100.99	99.73	99.04	99.84	101.42	101.00	100.90	
	F. .50 100.62 .22 100.40									
Sp. gr.	2.779 13°	....	....	3.401	....	....	2.974	3.227	3.268	....

	f Rock.	f Pyrox.	g Rock.	g Pyrox.	h Rock.	h Pyrox.	i Rock.	i Pyrox	j Rock.	j Pyrox.	k Pyrox.
SiO_2	50.41	51.27 .854	67.42	53.19 .886	53.73	46.72 .779	46.73	49.42 .824	47.61	47.54 .792	46.47 .774
Al_2O_3	12.30	3.05 .029	15.88	2.38 .023	20.35	2.41 .023	10.05	4.28 .042	14.26	4.14 .040	4.28 .042
Fe_2O_3	5.71	3.08 .019	1.37	9.25 .057	3.74	17.29 .108	3.53	2.86 .018	4.90	5.64 .035	5.95 .037
FeO	3.06	4.34 .060	1.14	5.15 .071	2.13	10.57 .147	8.20	5.56 .077	4.07	6.42 .089	12.17 .169
MgO	8.69	14.21 .355	1.43	9.43 .236	.47	2.57 .064	9.68	13.58 .339	2.62	10.05 .251	7.24 .181
CaO	7.08	22.58 .403	3.49	17.81 .318	2.72	13.51 .241	13.22	22.35 .399	8.71	21.57 .385	19.23 .343
Na_2O	.97	.67 .010	6.42	2.63 .042	7.94	4.88 .079	1.81	1.04 .017	6.70	1.38 .022	2.61 .042
K_2O	7.53	.06 .000	2.65	.38 .004	6.05	.48 .005	3.76	.38 .004	4.08	.12 .001	.74 .008
H_2O+	1.80	undet.	.05	.01	2.02	....	1.24	.09	1.89	undet.	....
H_2O-	.46	none		....	....	....	....	....	.26	none	....
TiO_2	1.47	.70 .009	....	....	.09	trace	.78	.55 .007	1.38	3.00 .037	.73 .009
P_2O_5	.46	....	.07	....	....	....	1.51	....	1.38	....	....
SO_3	none	....	....	....	....	....	....	....	1.17	....	....
Cl	trace	....	....	....	.23	....	.18	....	.37	....	....
Cr_2O_3	trace	none	....	....	....	....	....	....	trace ?	trace ?	....
NiO	.04	.03	....	....	....	....	....	....	trace	trace	....
MnO	.15	.28 .004	trace	....	.51	1.31 .019	.28	.10 .001	.30	.36 .005	....
BaO	.23	none	....	....	....	....	....	....	.41	none	....
SrO	.06	none	....	....	....	....	....	....	.36	none	....
Ce_2O_3, Di_2O_3	none	none	....	....	....	....	....	....	.18 S .03	none	....
	100.42	100.27	99.92	100.23	99.98	99.74	100.97	100.21	100.68	100.21	99.42
Sp. gr.	2.88 29°	3.45 25°	....	....	....	....	....	....	2.79 25°	3.43 28°	....

	l Rock.	l Pyrox.	m Rock.	m Pyrox.	n Rock.	n Pyrox.	o Rock.	o Pyrox.
SiO_2	45.59	49.26 .821	42.46	44.55 .742	39.92	45.23 .754	42.78	44.65 .744
Al_2O_3	12.98	6.01 .059	18.49	7.27 .071	8.60	7.73 .075	8.06	6.62 .065
Fe_2O_3	4.97	3.31 .020	3.35	6.06 .038	4.40	2.95 .018	....	5.02 .031
FeO	4.70	4.23 .059	6.31	5.91 .082	8.00	4.07 .056	17.96	3.87 .054
MgO	8.36	12.40 .310	3.64	10.44 .261	20.17	12.25 .306	10.06	14.76 .369
CaO	11.09	21.79 .389	8.70	22.83 .407	10.68	23.37 .417	12.29	20.32 .363
Na_2O	4.53	.79 .012	7.12	1.47 .023	1.91	.47 .007	2.31	1.29 .021
K_2O	1.04	.41 .004	4.58	.52 .006	1.03	.12 .001	.62	.49 .005
H_2O+	3.40	undet.	2.31	....	1.45	.37	3.96	....
H_2O-	.51	undet.	....	....	.43	....	....	....
TiO_2	1.32	1.53 .019	....	1.36 .019	2.70	4.28 .053	.28	2.93 .037
P_2O_5	.91	....	....	....	.51	none	....	....
SO_3	....	....	2.44	....	....	....	....	....
Cl	.05	....	.52	....	trace	....	....	....
Cr_2O_3	....	....	....	....	.14	....	....	....
NiO	....	....	....	....	.06	.05	trace	....
MnO	.14	undet.	....	....	.24	.07 .001	.95	....
BaO	.13	?	....	....	.06	none	....	....
SrO	.12	.06	....	....	.04	none	....	....
Ce_2O_3, Di_2O_3	.03	....	....	....	none S. trace V_2O_3 .04	....	....	
	99.87	99.79	99.92	100.41	F. .07	100.96	99.87	99.95
					100.45 .03 100.42			
Sp. gr.	....	....	....	3.416	....	....	2.829	3.411

	p Rock.	p Pyrox.	q Rock.	q Pyrox.	r Rock.	r Pyrox.	s Rock.	s Pyrox.	t Rock.	t Pyrox.
SiO_2	48.25	49.10 .818	43.74	44.55 .759	47.54	47.06 .784	47.83	45.67 .761	52.75	51.60 .860
Al_2O_3	16.73	7.95 .078	14.82	7.86 .077	16.73	7.77 .076	16.09	9.04 .088	22.55	1.92 .018
Fe_2O_3	3.99	trace	2.40	3.81 .024	6.69	1.30 .008	4.32	7.46 .046	3.65	26.29 .164
FeO	6.28	8.30 .115	7.52	4.53 .063	6.67	8.15 .113	3.62	2.00 .028	....	4.20 .058
MgO	5.77	12.37 .309	6.98	12.71 .318	6.38	13.52 .338	5.53	12.09 .302	.15	1.15 .029
CaO	8.32	22.54 .402	10.81	20.84 .336	8.74	19.33 .345	10.68	21.78 .389	1.85	4.25 .076
Na_2O	3.24	trace	3.08	1.29 .021	2.81	.33 .005	4.46	1.25 .020	8.10	8.89 .143
K_2O	4.08	trace	2.90	.49 .005	1.10	.11 .001	4.05	.56 .006	7.05	1.05 .011
H_2O+	1.72	....	2.94	....	.36	.20	.24	.31	3.60	.50
H_2O-	....	....	....	....	....	....	....	....		
TiO_2	.89	(?)	2.80	2.85 .036	2.76	1.82 .023	2.27	.62 .008		
P_2O_5	.68	....	.64	....	.51	.06	1.33			
SO_3	.12	.								
Cl	.08									
Cr_2O_3	....	....	....	....	....	trace				
NiO	....	....	....	....	....	trace				
MnO	trace	....	....	.38 .005	.19	.20 .003	trace			
BaO	.01	....	....	....	.03					
SrO	....	....	....	....	....					
Ce_2O_3, Di_2O_3			CO_2 .15							
	100.16	100.20	100.23	99.31	100.51	99.85	100.40	100.70	99.70	99.91
Sp. gr.		..	2.914	3.284		.	2.858	3.37		

a) *Diopside* from mixed wyomingite and madupite; rock analysis of *wyomingite* (felsophyro-wyomingose), Leucite Hills, Wyo. *A. J. S.*, Vol. IV (1897) p. 130.

b) *Diopside* (A. Merian) from *laurvikite* (grano-laurvikose) Byskoven near Laurvik, Norway. Brögger, W. C., *Eruptivgesteine Kristianiageb*, Vol. III, pp. 23 and 31.

c) *Diopside* from pyroxene-granitite, Laveline, Vosges, Rosenbusch, El. Gest., p. 73; rock analysis of *augite-granitite* (grano-adamellose), Laveline, Vosges, Rosenbusch (v. Werveke), *Neues Jahrb. Min. und Pal.*, etc. (1881), Vol. I, p. 235.

d) *Augite*, c:c=39° 30′, 2 H=87° 20′ } from coarse grained nephelite-basalt (grano-malignose).

e) *Augite*, c:c=34°, 2 Ha=84° 50′ (yellow) } Katzenbuckel, Odenwald. Rosenbusch, *El. Gest.*, pp. 354, 357.

f) *Augite* from *syenitic lamprophyre* (prowersose), Two Buttes, Colo. *Bull. 168, U. S. Geol. Surv.*, p. 165.

g) *Augite*, bottle green, in part colorless, with slight pleochroism, a and b bottle green, c yellowish green, a = b > c. c:a=37° for colorless, c:a=22° for green, from *augite-soda-granite* (grano-lassenose) Kekequabic Lake, Minn. *Am. Geol.*, Vol. XI (1893), p. 385.

h) *Aegirite-augite* from *nephelite-syenite* (grano-laurdalose), Zwart Koppies, Transvaal, Rosenbusch, *El. Gest.*, pp. 122, 126.

i) *Augite* from *shonkinite* (grano-shonkinose), Square Butte, Mont. Pirsson, *Bull. Geol. Soc. Am.*, Vol. VI (1895), pp. 410, 414.

j) *Augite* from *tinguaite* (?) (laurdalose), Two Buttes, Colo. *Bull. 168 U. S. Geol. Surv.*, p. 165.

k) *Aegirite-augite* from leucitophyre, Burgberg, near Rieden. Rosenbusch, *El. Gest.*, p. 278.

l) *Augite* from *analcite-basalt* (monchiquose), The Basin, Colo. *Bull. 168 U. S. Geol. Surv.*, p. 146, and Jour. Geol., Vol. V, p. 684.

m) *Augite*, yellow, c:c=39°, from *nephelinite* (hauynophyre) (vulturose), Melfi, Italy. Rosenbusch, *El. Gest.*, p. 357.

n) *Augite* from *nephelite-basalt* (uvaldose), Black Mountain, Uvalde county, Texas. *Bull. 168 U. S. Geol. Surv.*, p. 63.

o) *Augite* from *limburgite*, Limburg, Kaiserstuhl. Rosenbusch, *El. Gest.*, p. 363.

p) *Augite* from *dolerite* (shoshonose), Valmont, Colo. *Bull. 150 U. S. Geol. Surv.*, p. 264, and *Bull. 168 U. S. Geol. Surv.*, p. 140.

q) *Augite* from *monchiquite* (ourose), Rio do Ouro, Serra de Tingua, Rio de Janeiro. Rosenbusch, *El. Gest.*, pp. 234, 235.

r) *Augite* from *basalt* (auvergnose), six miles N. E. of Grants, N. M. *Bull. 168 U. S. Geol. Surv.*, p. 170.

s) *Augite* (c:c=54°) from *leucite-tephrite* (monchiquose), Falkenberg, near Tetschen, Bohemia. Rosenbusch, *El. Gest.*, p. 346.

t) *Aegirite* from *nephelite-syenite* (grano-janeirose), Barreros, rock analysis from tunnel between Prata and Cascada, Serra do Poços de Caldas, Las Paolo, Brazil. Rosenbusch, *El Gest.*, pp. 122, 126.

TABLE XIIa. MOLECULAR RATIOS IN PYROXENES.

			$\frac{Al_2O_3}{CaO}$	$\frac{Fe_2O_3}{CaO}$	$\frac{(NaK)_2O}{CaO}$	$\frac{MgO}{CaO}$	$\frac{FeO}{CaO}$	$\frac{SiO_2}{CaO}$	$\frac{TiO_2}{CaO}$	Femic	Salic	Deficient SiO_2
a) Diopside	phyro-wyomingose	Wyomingite	.00	.01	.03	1.04	.06	2.03	.09	1.00	.00	......
b) Diopside	grano-laurvikose	Laurvikite	.00	.00	.11	.69	.44	2.13	.02	1.00	.00	......
c) Diopside	grano-adamellose	Pyroxene-granitite	.02	.05	.05	.85	.31	2.22	.02	.986[1]	.014	—.017
d) Augite	grano-malignose	Nephelite-basalt	.04	.11	.21	.93	.14	2.66	.07	.95[1]	.05	.000
e) Augite	grano-malignose	Nephelite-basalt	.06	.16	.15	.97	.01	2.64	.12	.88[1]	.12	.000
f) Augite	prowersose	Syenitic lamprophyre	.07	.04	.03	.88	.16	2.11	.02	.91[1]	.09	.000
g) Augite	grano-lassenose	Augite soda granite	.07	.18	.14	.74	.22	2.78	.00	.83[1]	.17	.000
h) Aegirite-augite	grano-laurdalose	Nephelite-syenite	.09	.44	.34	.26	.01	3.23	.00	.87[1]	.13	.000
i) Augite	grano-shonkinose	Shonkinite	.10	.04	.05	.85	.19	2.06	.02	.90[1]	.10	—.038
j) Augite	laurdalose	Tinguaite (?)	.10	.09	.06	.65	.24	2.05	.10	.80[1]	.14	.000
k) Augite	no analysis	Leucitophyre	.12	.10	.14	.52	.49	2.25	.02	.88[1]	.12	—.013
l) Augite	monchiquose	Analcite-basalt	.15	.05	.04	.79	.16	2.11	.05	.82[1]	.18	.000
m) Augite	vulturose	Nephelinite	.17	.09	.07	.64	.20	1.82	.04	.82[1]	.18	—.053
n) Augite	uvaldose	Nephelite-basalt	.18	.04	.02	.73	.14	1.80	.13	.81[1]	.19	—.039
o) Augite	(poor analysis)	Limburgite	.18	.08	.07	1.01	.15	2.05	.10	.84	.16	—.040
p) Augite	shoshonose	Dolerite	.19	.		.77	.28	2.03	..	.81	.19	—.036
q) Augite	ourose	Monchiquite	.22	.07	.07	.94	.20	2.26	.10	.82[1]	.18	.007
r) Augite	auvergnose	Basalt	.22	.02	.02	.98	.33	2.27	.70	.79[2]	.21	.000
s) Augite	monchiquose	Leucite-tephrite	.22	.11	.06	.72	.14	1.95	[illegible]	.76[1]	.24	.028
t) Aegirite	grano-janeirose	Eleolite-syenite	.23	2.16	2.02	.38	.76	11.31	.00	.86[1]	.14	.000

[1] All femic Ca, Mg, Fe calculated as metasilicate.

[2] Femic Ca, Mg, Fe calculated partly as orthosilicate and partly as metasilicate. Deficient SiO_2 is that required to raise part of the salic components to leucite or nephelite.

	a			*n*		*o*	*p*	
	Rock.	Hornbl.	Rd-.	Rock.	Cossyrite.	Ainigmatite.	Rock.	Amphibole.
SiO_2 ...	66.83	47.49	6	70.30	43.55	37.92	74.76	49.10
		.791	1		.726	.632		.818
Al_2O_3..	15.24	7.07	1	6.32	4.96	3.23	11.60	5.50
		.069	3		.048	.031		.054
Fe_2O_3 ..	2.73	4.88		9.23	7.97	5.81	3.50	4.20
		.030	4		.045	.036		
FeO	1.66	10.69		1.40	32.87	35.88	.19	27.70
		.148	4		.456	.498		.385
MgO...	1.63	13.06		.89	.86	.33	.18	.17
		.326	5		.021	008		.004
CaO....	3.59	11.92		.84	2.01	1.36	.07	.13
		.213	3		.036	.024		.002
Na_2O ..	3.10	.75		7.70	5.29	6.58	4.35	10.50
		.012			.085	.106		.169
K_2O ...	4.46	.49		2.50	.33	.51	4.92	1.60
		.005			.003	.005		.017
H_2O+ .	.56	1.86		.82	....	....	.64	....
H_2O- .	none	....		....	....	....	....	...
CO_2....	....	....		....	....	....	....	....
TiO_2...	.54	1.21		....	....	7.57	trace	....
		.015				.094		
P_2O_5...	.18	none		....	....		trace	....
SO_3. ...	....	....		...	....		....	....
Cl......	.02	....	t	....	....	....	...	....
Cr_2O_3..	....	none		....	....	....	....	....
NiO	....	.02		....	....	....	....	....
MnO...	.10	.51		....	1.98	.100	....	.50
		.007			.027	.013		.007
BaO....	.11	none		....	....	....	....	....
SrO	.03	none		....	....	....	...	....
ZrO_2...	.04	F.06		....	CuO.39	...	....	...
	100.82	V_2O_3.04	9	100.00	100.21	100.19	100.21	99.40
		100.05			3.74	3.80	....	....
		.02			3.75	3.852	....	....
		100.03						

a) *Hornblende* from quart grano-liparose), Quincy, Blue Hills, Mass., analysis from *quartz-* p. 181.

Yosemite Valley, Cal *ite*, San Miguel, Azores, ROSENBUSCH, *El. Surv.*, p. 208, and *A*

b) *Hornblende* from *quartz* *elite-syenite*, Kangerdluarsuk, Greenland, tion, Butte, Mont. *E*, p. 122.

c) *Hornblende* (green) from *pantellerite* (felso-varingose) Khartibugal, *blende-dacite* (ban H, *El. Gest.*, p. 257.

Gata, Spain, ROSENB *e-syenite*, Julianehaab, Greenland, ROSEN-

d) *Hornblende* from *quart*.

Table Mountain, Cal (felso-liparose), San Pietro, Sardinia, ROSEN-

;fi-
nt
)$_2$

ooo
ooo
oo7
o14
oo3
o95
ooo
ooo
o40
165
ooo
o30
ooo
ooo
ooo
ooo

TABLE XIII. ANALYSES OF AMPHIBOLES AND THE ROCKS CONTAINING THEM.

	a Rock.	*a* Hornbl.	*b* Rock.	*b* Hornbl.	*c* Rock.	*c* Hornbl.	*d* Rock.	*d* Hornbl.	*e* Rock.	*e* Hornbl.
SiO_2	66 83	47.49 .791	63.88	45.73 .762	62 21	45.76 .762	54.64	50.08 .835	47 27	46 08 .768
Al_2O_3	15 24	7.07 .069	15 84	6 77 .066	15 60	8.80 .086	12.06	7.97 .078	20.82	10.52 .103
Fe_2O_3	2.73	4.88 .030	2.11	4.94 .031	5.26	5.32 .033	1.81	2.69 .016	1.85	2.81 .017
FeO	1.66	10.69 148	2.59	10.39 .144	1.36	11.23 .156	5.03	6.71 .093	4.26	8.30 .101
MgO	1.63	13.06 .326	2.13	12.32 .308	2.61	14.08 .352	11.86	16.31 .408	6.44	14.40 .360
CaO	3.59	11.92 .213	3.97	11.25 .201	6.55	10.62 .189	7.74	11.21 .200	13.02	12.64 .226
Na_2O	3.10	.75 .012	2.81	.77 .012	2.50	1.39 .022	2.35	1.22 .019	2.75	1.62 .026
K_2O	4.46	.49 .005	4.23	1.22 .013	1.63	.26 .003	1.01	.46 .005	.22	.34 .004
H_2O+	.56	1.86	.66	2.29	2.25	.85	2.44	1.40	1.27	1.97
H_2O	none	....	.22	.49	....	....	.12	....	.08	.17
CO_2	....	....	....	....	....	....	....	....	....	....
TiO_2	.54	1.21 .015	.65	1.43 .018	....	1.43 .018	.61	.76 .009	.92	.77 .009
P_2O_5	.18	none	.21	.35 002	....	....	.08	trace	.74	.18
SO_3	..	...	34	...	.	..	.	.	...	..
Cl	.02	....	trace	....	....	....	....	....	trace	....
Cr_2O_3	.	none	....	....	....	....	....	.16	trace	....
NiO	....	.02	....	....	....	....	.05	....	....	....
MnO	.10	.51 .007	.07	.54 .008	....	.57 .008	.13	.49 007	trace	.15 .002
BaO	.11	none	.09	none	....	....	.05	none	....	....
SrO	.03	none	.02	none	....	....	trace	....	trace	....
ZrO_2	.04	F.06	....	....	....	....	V_2O_3.03	....	V_2O_3.02	.04
	100.82	V_2O_3.04	99.82	F. .28 015	99.97	100.31	100.01	100.46	99.86	99.99
		100.05 .02		98.77 .12	Sp. Gr.	3.212				
		100.03		98.65						

	f Rock.	*f* Hornbl.	*g* Hornbl.	*h* Rock.	*h* Hornbl.	*i* Hastingsite.	*j* Rock.	*j* Barkevikite.
SiO_2	59.22	39.62 .660	41 35 .689	59.37	46 22 .770	34.18 .569	56.45	38.41 6.40
Al_2O_3	13.59	14.92 1.46	13.48 .132	17.92	8.12 .079	11.52 .113	20.08	16.39 * .160
Fe_2O_3	5.55	10.28 .094	5.14 .032	6.77	9.33 .058	12.62 .079	1.31	3.75 .023
FeO	4.03	7.67 .106	10.33 .143	2.02	15.18 .210	21.98 .305	4.39	21.75 .302
MgO	1.66	11.32 .283	11.44 .286	1.83	5.20 .130	1.35 .034	.63	2.54 .063
CaO	5.13	12.65 .226	10.93 .195	4.16	10.08 .180	9.87 .176	2.14	10.52 .188
Na_2O	5.31	1.12 .018	2.10 .034	1.24	2.46 .039	3.29 .053	5.61	2.95 .047
K_2O	4.64	2.18 .023	.62 .007	6.68	1.23 .012	2.29 .024	7.13	1.95 .020
H_2O+	1.25	.48	.48	.38	1.36	.35	1.51	.24
H_2O	....	....	....	....	....	....	.26	....
CO_2	....	....	....	....	....	....	....	.
TiO_2	....	.19 .002	4.97 .062	.26	1.08 .013	1.53 .019	29	1 26* 018
P_2O_5	....	....	....	.58	....	....	.13	....
SO_3	...	...	.	..	.	.	. .	....
Cl	...	....	....	....	....	....	.43	
Cr_2O_3	....	....	....	....	....	....	....	
NiO	....	....	....	....	...	....	trace	trace
MnO	....	.24 .003	....	....	....	.63 .009	.09	.15 .002
BaO	....	....	....	...	....	....	....	....
SrO	....	....	....	....	....	....	....	..
ZrO_2	....	....	....	....	....	....	....	..
	100.38	100.67	100.84	101.21	100.26	99.61	100.45 .10	99.91
	2.74	3.266	3.25	2.710	3.157	3.433	100.35	3.437

	k Rock.	*k* Riebeckite.	*l* Katophorite.	*m* Arfvedsonite.	*n* Rock.	*n* Cossyrite.	*o* Ainigmatite.	*p* Rock.	*p* Amphibole.
SiO_2	73.93	49.65 .827	45.53 .759	43.85 .731	70.30	43.55 .726	37.92 .632	74.70	49.10 .818
Al_2O_3	12.29	1.34 .013	4.10 .040	4.45 .043	0.32	4.96 .048	3.23 .031	11.60	5.50 .054
Fe_2O_3	2.91	17.66 .110	9.35 .058	3.80 .024	9.23	7.97 .045	5.81 .036	3.50	4.20
FeO	1.55	19.55 .271	23.72 .301	33.43 .464	1.40	32.87 .456	35.88 .498	.19	27.70 .385
MgO	.04	....	2.46 .061	.81 .020	.89	.86 .021	.33 008	.18	17 004
CaO	.31	3.16 .056	4.89 .087	4.65 .083	.84	2.01 .036	1.36 .024	.07	13 002
Na_2O	4.66	7.61 .122	6.07 .098	8.15 .131	7.70	5.29 .085	6.58 .106	4.35	10.50 .169
K_2O	4.63	....	.88 .009	1.06 .011	2.50	.33 .003	.51 .005	4.92	1.60 017
H_2O+	....	1.67	....	.15	.82	....	....	.64	
H_2O	.41	....	....	....	..	.	....	...	.
CO_2	.	...	....	..	....	..	...	..	
TiO_2	.18	...	..	...	.		7 57 094	trace	....
P_2O_5	....	....	....	....	....	....		trace	
SO_3	....	....	...	....	.			....	..
Cl	....	....	....	....	...	..	...	..	..
Cr_2O_3	....	....	....	...	....	.	....	..	..
NiO	....	..		.	...	...	.	..	.
MnO	trace	....	2.96 .041	.45 .006	..	1.98 .027	.100 .013	....	.50 .007
BaO	none	..	....	....	..	..	.	....	...
SrO	...	...	...	....	....	....	..	...	...
ZrO_2	...	..	..	.		CuO.39	..	...	
	100.91	100.64	99.96	100.80	100.00	100.21	100.19	100.21	99.40
	2.642		3.43	3.44		3 74 3 75	3 80 3.852	....	.

*Al_2O_3 and TiO_2 estimated from rock analysis. Al_2O_3 determined as 17.65 including TiO_2.

a) *Hornblende* from quartz-monzonite, S. E. Mt. Hoffmann, Cal.; rock analysis from *quartz-monzonite* (grano-toscanose), Nevada Falls Trail, Yosemite Valley, Cal. (average rock of region). *Bull. 168 U. S. Geol. Surv.*, p. 208, and *A.J.S.*, Vol. VII, (1899), p. 297.

b) *Hornblende* from *quartz-monzonite* (grano-amiatose), Walkerville Station, Butte, Mont. *Bull. 168, U. S. Geol. Surv.*, p. 116.

c) *Hornblende* (green) from *dacite*, Grenatilla, rock analysis from *hornblende-dacite* (bandose), San Pedro, Sierra del Cabo, Cabo de Gata, Spain, Rosenbusch, *El. Gest.*, pp. 285, 286.

d) *Hornblende* from *quartz-diorite* (grano-camptonose), 46 miles south of Table Mountain, Cal. *Bull. 168 U. S. Geol. Surv.*, p. 190.

e) *Hornblende* from *hornblende-gabbro* (grano-hessose), Beaver Creek, Big Tree Quadrangle, Cal. *A. J. S.*, Vol. VII (1899), p. 297.

f. *Hornblende* from *andesite* (umptekose), Stenzelberg, Siebengebirge, Rosenbusch, *El. Gest.*, pp. 290, 292.

g. *Hornblende* from "hornblende-diabase," Gräveneck, near Weilberg. Rosenbusch, *El. Gest.*, p. 306.

h) *Hornblende* from *syenite*, Biella, Piedmont, Italy, Rosenbusch, *El. Gest.*, pp. 103, 106.

i) *Hastingsite* (deep blue) from *nephelite-syenite*, Dunganon, Ontario, Rosenbusch, *El. Gest.*, p. 122.

j. *Barkevikite* from *sodalite-syenite* (grano-pulaskose), Square Butte, Mont. *A. J. S.*, Vol. XLV, 1893, p. 292.

k) *Riebeckite from granite* (grano-liparose), Quincy, Blue Hills, Mass., *A. J. S.*, Vol. VI, 1898, p. 181.

l) *Katophorite* from *sanidinite*, San Miguel, Azores. Rosenbusch, *El. Gest.*, p. 266.

m) *Arfvedsonite* from *nephelite-syenite*, Kangerdluarsuk, Greenland, Rosenbusch, *El. Gest.*, p. 122.

n) *Cossyrite* (ainigmatite) from *pantellerite* (felso-varingose) Khartibugal, Pantellaria, Rosenbusch, *El. Gest.*, p. 257.

o) *Ainigmatite* from *nephelite-syenite*, Julianehaab, Greenland, Rosenbusch, *El. Gest.*, p. 122.

p) *Amphibole* from *comendite* (felso-liparose), San Pietro, Sardinia, Rosenbusch, *El. Gest.*, p. 257.

TABLE XIIIa. MOLECULAR RATIOS IN AMPHIBOLES.

Minerals.	Rocks.		$\frac{Al_2O_3}{CaO}$	$\frac{Fe_2O_3}{CaO}$	$\frac{(Na,K)_2O}{CaO}$	$\frac{MgO}{CaO}$	$\frac{FeO}{CaO}$	$\frac{SiO_2}{CaO}$	$\frac{TiO_2}{CaO}$	Femic.	Salic.	Deficient SiO_2
a Hornblende	grano-toscanose	Quartz-monzonite	.32	.14	.08	1.53	.69	3.71	...	.77[1]	.23	.000
b Hornblende	grano-amiatose	Quartz-monzonite.	.32	.15	.12	1.53	.71	3.79	....	.77[1]	.23	.000
c Hornblende	grano-bandose	Dacite.	.45	.17	.13	1.86	.82	4.03	.09	.76[1]	.24	—.007
d Hornblende	grano-camptonose	Quartz-diorite	.39	.08	.12	2.04	.46	4.17	....	.78[1]	.22	—.014
e Hornblende	grano-hessose	Gabbro	.45	.07	.13	1.60	.44	3.46	....	.71[2]	.29	—.003
f Hornblende	grano-umptekose	Andesite (?) trachyte	.64	.41	.18	1.25	.47	2.92	....	61[1]	.39	—.095
g Hornblende	no analysis	Diabase	.67	.16	.21	1.46	.73	3.53	.31	.57[2]	.43	.000
h Hornblende	(?) analysis	Syenite.	.44	.32	.28	.72	1.16	4.28	.07	.66[1]	.34	.000
i Hastingsite	no analysis	Nephelite-syenite	.64	.45	.43	.33	1.60	3.23	.10	.67[2]	.33	—.040
j Barkevikite	grano-pulaskose	Sodalite-syenite.	.85	.12	.35	.19	1.73	3.40	....	.62[2]	.38	—.165
k Riebeckite	grano-liparose	Soda granite	.23	1.9	2.18	.0	4.84	14.76	....	.94[1]	.06	.000
l Katophorite	no analysis	Sanidinite	.46	.66	1 23	.70	3.46	8.72	....	.82[2]	.18	—.030
m Arfvedsonite	no analysis	Nephelite-syenite	.51	.29	1.71	.24	5 59	8.80	...	.81[2]	.19	.000
n Ainigmatite	felso-varingose	Pantellerite.	1.3	1.3	2.4	.58	12.60	20.01	....	.76[2]	.24	.000
o Ainigmatite	no analysis	Nephelite-syenite.	1.3	1.5	4.6	.33	20.75	26.33	3.9	.84[2]	.16	.000
p Amphibole	felso-liparose	Comendite	27.0	18.0	93.0	2.0	192.	409.	....	.71[1]	.29	.000

[1] All Femic Ca, Mg, Fe, calculated as metasilicate. [2] Femic Ca, Mg, Fe, calculated partly as orthosilicate and partly as metasilicate.

Deficient SiO_2 is that required to raise part of the salic components to leucite or nephelite.

TABLE XIV. ANALYSES OF MICAS AND THE ROCKS CONTAINING THEM.

	a		b		c		d		e		f		g		h		i	j	
	Rock.	Mica.	Rock.	Mica.	Rock.	Mica.	Rock.	Mica.	Rock.	Mica.	Rock.	Mica.	Rock.	Mica.	Rock.	Mica.	Mica.	Rock.	Mica.
SiO_2	71.08	36.02 .600	66.83	35.75 .596	63.88	35.79 .596	66.91	35.62 .594	77.61	31.96 .533	60.39	32.09 .535	54.55	34.37 .574	56.26	33.24 .554	36.42 .607	50.23	[illegible]
Al_2O_3	15.90	18.81 .184	15.24	14.70 .144	15.84	13.70 .134	....	15.24 .149	11.94	11.93 .117	22.57	18.52 .180	19.07	6.84 .067	13.59	14.90 .146	17.92 .175	11.22	[illegible] 119
Fe_2O_3	.62	5.60 .035	2.73	4.65 .029	2.11	5.22 .032	....	4.69 .029	.55	8.06 .050	.42	19.49 .121	2.41	24.89 .156	.85	5.92 .037	2.83 .017	3.34	[illegible] .012
FeO ...	1.31	14.75 .205	1.66	14.03 .195	2.59	13.72 .190	....	13.67 .190	.87	30.35 .421	2.26	14.10 .196	3.12	7.47 .104	2.61	23.57 .327	7.04 .098	1.84	[illegible] .012
MgO	.54	9.82 .245	1.61	12.27 .309	2.13	12.13 .303	....	12.70 .317	trace	.05 .001	.13	1.01 .025	1.98	4.05 .101	.27	5.15 .129	20.52 .513	7.09	[illegible]
CaO ..	2.60	.65 .011	3.59	.17 .003	3.97	.05 .001	3.51	.95 .017	.31	.23 .004	.32	....	3.15	.78 .014	.54	.40 .007	....	5.99	[illegible]
Na_2O	3.54	.38 .006	3.10	.32 .005	2.81	.15 .002	3.59	.50 .008	3.80	1.54 .025	8.44	1.55 .025	7.67	2.13 .034	7.77	1.45 .023	2.60 .042	1.37	[illegible]
K_2O .	4.08	9.32 .099	4.46	9.19 .098	4.23	9.09 .097	3.13	7.72 .082	4.98	8.46 .090	4.77	8.12 .086	4.84	9.03 .096	5.72	7.77 .082	6.54 .069	9.81	[illegible] 114
H_2O+	.30	2.57 .143	.56	3.64 .200	.66	3.64	....	4.36 .242	trace	4.25	.57	4.62 .256	.72	2.27 .127	.37	2.19	2.50	1.72	[illegible]
H_2O	none		none	1.03	.22	1.21	....	.94	.23	....	....	....	....	....	....	....	....	.93	
CO_2 ..	trace		trace	.	...	....	....	....	....	....	....	....	....	.	1.37	....	....	....	
TiO_2	.22	1.13 .014	.54	3.10 .039	.65	3.51 .044	....	2.61 .033	.25	3.42 .043	....	....	1.40	4.68 .058	.47	4.73 .059	3.99 [illegible]	2.27	[illegible]
P_2O_5	.10	..	.18	.03	.21	.10	....	none	....	...	....	....	.74	....	....	....	....	1.89	
SO_3 .	none	.	none		.34	....	....	....	....	....	....	....	....	....	....	....	....	.74	
Cl	.02		.02		trace	.20	....	....	.	....	....	....	....	....	....	....	....	.03	
Cr_2O_3 .		.		trace	...	...	....	....	....	....	....	....	.. .	....	....	....	....	.10	[illegible]
NiO .				.07	...	....	....	....	....	....	....	....		....	....	....	....		[illegible]
MnO	.15	.80 .011	.10	.45 .006	.07	.19 .002	....	.74 .010	trace	.21 .003	.08	1.42 .020	.17	2.41 .034	.09	.95 .013	....	.05	
BaO	.04	trace	.11	.12	.09	.13	....	.....	....	....	....	....	....	....	....		....	1.23	1.00
SrO	.02	none	.03	(?)	.02	none	....	trace	....	....	....	F. none	....	....	....	....	....	SrO .24	trace
ZrO_2.....	.08	F. .26 .014	ZrO_2 .04	none	....	F. .76 .032	....	....	....	....	....	....	....	....	....	...	....	Di_2O_3 .03 1. 50	.... [illegible]
	100.60	100.11	100.82	F. .17	99.82	99.59		100.00	100.54	100.46	99.95	100.92	99.82	98.92	99.91	100.27	[illegible]	[illegible]	[illegible]
				V_2O_3 .05											Sp. gr..	3.084		[illegible]	[illegible]
				99.90															
				.07															
				99.83															

a) *Biotite* from *granodiorite* (grano-toscanose), El Capitan, Yosemite Valley, Cal. *A. J. S.*, Vol. VII (1899), p. 294.

b) *Biotite* from *quartz-monzonite* (grano-toscanose), Nevada Falls Trail, Yosemite Valley, Cal. *A. J. S.*, Vol. VII (1899), p. 297, and *Bull. 168, U. S. Geol. Surv.*, p. 208.

c) *Biotite* from *quartz-monzonite* (grano-amiatose), Walkerville Station, Butte, Mont. Jour. Geol., Vol. VII, and *Bull. 168, U. S. Geol. Surv.*, p. 116.

d) *Biotite* from *quartz-monzonite* (grano(?)toscanose), Bloods Station, Alpin Co., Cal. *A. J. S.* Vol. VII (1899), p. 294.

e) *Lepidomelane* from *granite* (grano-liparose), Cape Ann, Mass. *A. J. S.*, Vol. XXXII, 1886, p. 359. Rock analysis, H. S. Washington, Jour. Geol., Vol. VI, p. 793.

f) *Lepidomelane* from *nephelite-syenite* (grano-nordmarkose), Litchfield, Me. *Bull. 168, U. S. Geol. Surv.*, p. 21.

g) *Lepidomelane* from syenite-pegmatite, Barkevik, Langesundfjord, Norway; rock analysis from *laurdalite* (laurdalose), north of Löve, Laugenthal. Brögger, *Eruptivgest. Kristiania geb.* III, pp. 19 and 34.

h) *Lepidomelane* from (?) nephelite-syenite, Miask, Dana, System, p. 630; rock analysis from *miascit* (grano-miaskose), Mt. Lobatchia, Siberia. A. Karpinski, *Guide Excurs. VII, Cong. Geol. Int.* V (1897), p. 22.

i) "Biotite" from monchiquite, Horberig, Oberbergen. Rosenbusch, *El. Gest.*, p. 234.

j) *Phlogopite* from wyomingite (phyro-wyomingose), Boar's Tusk, Leucite Hills, Wyo. *A. J. S.*, Vol. IV (1897), p. 130, and *Bull. 168, U. S. Geol Surv.*, p. 85.

TABLE XIVa, MOLECULAR RATIOS IN MICAS.

			$\frac{Al_2O_3}{K_2O}$	$\frac{Fe_2O_3}{K_2O}$	$\frac{MgO}{K_2O}$	$\frac{FeO}{K_2O}$	$\frac{SiO_2}{K_2O}$	$\frac{TiO_2}{K_2O}$	Femic.	Salic.	Deficient. SiO_2.
a) Biotite	grano-toscanose	Granodiorite..................	1.8	.33	2.47	2.07	5.71	.13	.54	.46	
b) Biotite..........	grano-toscanose..............	Quartz-monzonite.............	1.4	.28	3.15	2.00	5.78	.38	.52	.48	
c) Biotite.................	grano-amiatose	Quartz-monzonite.............	1.3	.32	3.12	1.96	6.01	.44	.52	.48	
d) Biotite......................	no analysis	Quartz-monzonite.............	1.9	.32	3.86	2.31	6.60	.36	.54	.46	
e) Lepidomelane.......	grano-liparose	Granite	1.0	.43	.0	4.67	4.63	.37	.55	.45	
f) Lepidomelane	grano-nordmarkose............	Nephelite-syenite	1.6	1.1	.29	2.28	4.82	...	.40	.60	
g) Lepidomelane...............	grano-laurdalose	Nephelite-syenite	.51	1.2	1.05	1.07	4.26	.44	.62	.38	
h) Lepidomelane...............	grano-miaskose	Nephelite-syenite	1.4	.35	1.57	3.98	5.27	.56	.53	.47	
i) "Biotite"............ .. .	no analysis..............	Monchiquite.........	1.5	.15	7.42	1.42	5.46	.44	.52	.48	
j) Phlogopite..................	phyro-wyomingose.............	Wyomingite	.98	.14	4.91	.10	5.86	.21	.49	.51	

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CARTOGRAPHIC REPRESENTATION OF GEOLOGICAL FORMATIONS.

As CARTOGRAPHIC units, in the representation of geological structure, the lithologic individual, the faunal stage and the geological formation are commonly regarded as practically identical. In reality, they are fundamentally distinct from one another. Moreover, these are not the only units which it is possible and practicable to map and bring out clearly the geological structure of the area investigated.

In the recent discussions on the units of geological mapping, one of the most important fundamental factors appears to be entirely overlooked. The two leading phases of the subject are admirably summed up in the recent articles of Messrs. Willis[1] and Cross.[2] Although, at first glance, these authors seem to present radically different views, they are not, actually, so far apart in their contentions as they would have us believe. Mr. Cross' conception is the more philosophical of the two; it is based on genetic grounds; and it is the one which must finally prevail, though the local criteria of discrimination may be diverse in different cases. In actual practice, Mr. Willis' expressed idea has the greater force and must be the one which must necessarily long be followed. But the two conceptions are not incompatible. In the practical application of the principles, the final results become very nearly identical.

To every one who has given the subject critical attention, it

[1] JOUR. GEOL., Vol. IX, p. 557, 1901. [2] *Ibid.*, Vol. X, p. 223, 1902.

must be quite evident that no standard yet proposed for the delimitation of geological units in cartographic representation exactly expresses the essential features of a complete and rational scheme. As in all classifications of natural objects, that of geological units, formations, or terranes should be in its highest type genetic in character. Moreover, it should be strictly stratigraphic, depositional or sequential, using these terms in their broadest sense to include all rock-masses, igneous, metamorphic and sedimentary. With this understanding of the theme, the most obvious characteristic of a stratigraphic scheme is not the terranes or rock-masses themselves, nor any of their contents, but their geometric elements, their bounding or stratigraphic planes. In order not to carry with it the usual narrow idea, some such term as depositional or sequential planes should be used in place of the name stratigraphic, and these titles will be hereafter given preference. The sequential, depositional or sedimentation planes have different taxonomic values according to the general scheme of classification adopted[1].

A cross-section of the cartographic units, or geological formations, as they occur in nature, may be represented by the following sketch :

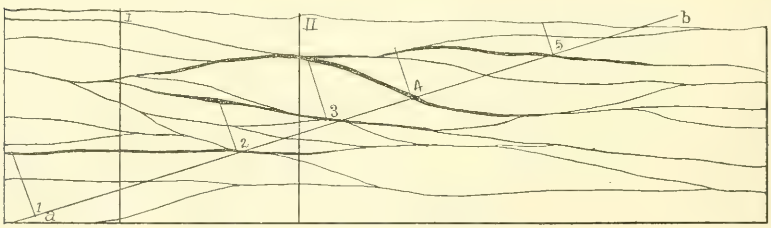


FIG. 1.—Geologic units in cross-section.

In the general, abstract or ideal instance, each lens-shaped figure is the unit established "with regard to all the facts and conditions of the case, and not upon the restricted basis of any part of those facts. It represents as much of the geological development of the earth recorded in the area covered as is practicable." The net-work of formations coincides with the

[1] *American Geologist*, Vol. XXIV, p. 294, 1899.

lines and planes of sedimentation, or natural sequence, to use a more comprehensive term. It gives a foundation for determining geologic structures and deciphering geologic events. This foundation is the same as that governing sedimentation and the sequential arrangement of rock-masses. The scheme is, therefore, genetic. It is of secondary importance to consider the composition and contents of the various lens-shaped figures. In some cases most value must be placed upon the lithologic character of a terrane. In other instances, the contained fossils, or minerals, are the determining factors. Under certain conditions still different features must be taken into consideration. The cardinal fact to be always recognized is that the cartographic unit, the geologic formation, is essentially an abstract conception. It may also be a lithologic, or faunal, or mineralogic, or physiographic, or some other kind of unit capable of being represented on maps.

As a matter of fact the lithologic features, the faunal characters, the mineralogic contents, as well as many other criteria of discrimination, are so grouped genetically to the depositional units which it is desired to represent on the map, that if the decipherable record of each were perfect, a cartographic representation of the one set of facts would in a general way indicate the probable outline of each of the other sets. But the fact that the records of all of these groups of data for the determination of the geologic formations are at best comparatively so meager, makes it incumbent upon the geologist to delimit his cartographic units at first according to the most obvious features presented in the several areas covered.

It so happens that in the field the most obvious and most useful single feature in recognizing and tracing a geological formation is the lithologic. Checked by other criteria, then, the lithologic unit corresponds very closely to the ideal cartographic unit established. For all practical purposes for which the geologic map is constructed lithologic individuals are amply sufficient and accurate. When more refined investigation is taken up some slight changes in the lines of formational delimitation may be necessary; but if the lithologic determinations

have been made with ordinary care it will probably be rare that radical alteration will be demanded.

In the present stage of geologic inquiry it is neither practicable nor desirable to map all districts with uniform refinement. Among geological formations, we shall no doubt eventually establish and indicate on all geological maps about five degrees of taxonomic rank. The division lines in any one area can only be fixed after very careful comparisons with those of all the neighboring districts. In the main, these terranal lines will be found to correspond to, or can easily be adjusted to, the divisional lines separating the lithologic individuals ordinarily recognized.

When the lithologic features of formations gradually merge into those of others, or when there is a rapid alternation of different kinds of rock layers, fossils or minerals, other criteria may have to be resorted to in order to properly delimit the terranes. But this fact certainly in no way invalidates the general principles involved in the recognition of the lithologic individual as the leading object to be represented in cartography.

When, for example, it was found upon detailed faunal examination[1] that the great St. Clair limestone of Arkansas, which had long been considered by the workers of that state as a single lithologic unit, was in reality two great limestones of almost identical lithologic appearance, the one Ordovician in age, and the other Silurian, it did not render worthless the maps upon which these two terranes had been represented as a single cartographic unit. Nor is the principle of mapping the lithologic individual to be given up on this account. Early observation was merely insufficient.

In the case of the ferruginous sandstone of southeastern Missouri and southwestern Illinois there is not a single continuous stratum, but a large number of disconnected deposits, lithologically indistinguishable, and lying, at least, at two very different geologic horizons. One horizon is below the Kaskaskia limestone and the other above that great rock-mass. The one is early Carboniferous; the other mid-Carboniferous. The lower continuous terrane is known as the Aux Vases sandstone; the

[1] *Am. Jour. Sci.* (3), Vol. XLVIII, p. 327, 1894.

other is formed by the basal sandstones of the Coal-measures. Farther southward, in Arkansas, the difference in the stratigraphic horizons of the two is upwards of 20,000 feet. Yet, because of peculiarities of position, the existence of an intervening unconformity plane, and the nearly same level above the sea of neighboring outcrops, of the two horizons on the Mississippi river, Worthen[1] and others were led to erroneously ascribe to the Kaskaskia (Lower Carboniferous) an extensive flora of the Coal-measures.

A different example is that of the Carboniferous of Arkansas. There is the enormous thickness of 26,000 feet of sediments. Sedimentation has been uninterrupted throughout the entire sequence. In the last formed terrane of the Lower Carboniferous, there begins an alternation of sandstones and shales, with some coal seams, continuing to the top of the section. About 24,000 feet of this section may be regarded as a lithological individual quite "uniformly varied in character." Data obtained farther north in Missouri show that 23,000 feet of this enormous section are unrepresented. The Arkansas section belongs to at least three great terranes, each having a taxonomic rank of series. Measured in feet, the median one alone is five times as great as all the rest of the Carboniferous represented in the Continental Interior. The conditions presented are represented below. Viewed from Arkansas alone the lines separating the distinct geological formations might forever remain unnoticed in the great lithologic individual. It is only by a comparison with sections in other localities that the terranal divisional lines may be properly drawn.

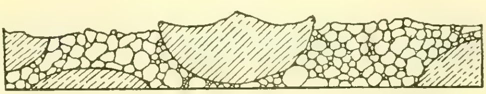


FIG. 2.—Carboniferous Sedimentation in Mississippi Valley.

There seems to be only one answer to the question: "What should a geological map represent?" That is Mr. Cross' observation that "it should represent as much of the geologic development of the earth recorded in the area covered as is practicable."

[1] *Illinois Geol. Surv.*, Vol. I, p. 79, 1866.

In considering every unit that is a possible basis for cartographic representation, a number of conditions have to be fully satisfied, in order that the best results may be obtained. As nearly as possible the unit adopted should be an abstract one, since schemes which have been elaborated, or may be in the future proposed, may not have different factors or different kind of factors to appose when the new facts are compared. The unit should be practically adaptable in order that knowledge once acquired may not have to be worked over anew in the field with each change of ideas necessitated by the constantly increasing use of more and more refined methods. The unit should be elastic, because too great rigidity of plan often breaks down the best of schemes. The unit should be easily recognizable and rapidly delimitable in the field; it should be of such character as to be readily traced from point to point, quickly run in on the map, and easily followed on the ground by subsequent investigators who may use the map.

It has been asserted that the lithologic map is a return to the so-called geological map of a century ago. It does not appear that the facts of the case warrant this statement. The geological map of today based strictly upon lithologic individuals is very nearly as fundamentally distinct from the mineralogical map of a hundred years ago, as is the modern map in which so-called geological formations are depicted. In mapping the geological features of an extensive region, work such as the federal government and some of the state geological surveys are engaged upon, the lithological individual for cartographic representation necessarily takes precedence over all other features. It will be a long time after the geological map based upon lithology principally is ready to be issued, that the perfected map of ideal geological formations can be made. In the majority of cases the delimitation of the latter must always rest very largely on the lithologic characters. A map of units recognizable in the field only after about as much study as was devoted to the terranes in the first place by the expert stratigrapher is of small practical use.

For a long time yet in modern areal work, the lithologic indi-

vidual, delimited if necessary by the aid of other criteria, appears amply comprehensive and exact for all purposes to which the ordinary geological map is put. As an aid in the development of the mineral resources of the country — the primary object of work of this kind — maps in which the lithologic individual is the unit amply suffice. In practice in the field, the units broadly defined by the lithologic characters, and those indicated by the more philosophical geologic formations, are generally near enough alike to enable future investigators to do their work without hindrance or uncertainty.

The suggestion of a faunal map eventually following the lithologic map as an integral part of a complete geologic atlas appears somewhat infelicitous. There is certainly no room whatever for such a dual plan in mapping. Such a scheme merely leads to others, maps based upon every criterion known or which may be devised. This is a proposition for which there is not the slightest demand. It is beyond all probability that parallel subdivisions should ever be found that are based upon radically different criteria. When we consider a dual scheme with a structural phase and a time phase based entirely upon fossils we are considering incongruous things. And there is not necessarily any logical connection.

In Europe, there is a classification generally presented that is dual in character, though with singular nomenclature. Thus, all the subdivisions of terranes and of time are strictly paralleled. The International Geological Congresses have adopted the same plan. It must be quite evident to the practical field geologist that there are very serious objections to this scheme. The critical criteria in the rock-scheme and in the time-scheme are fundamentally distinct. In fact, they have no genetic relationships whatever.

In reality, we have more than a dual scheme of classification in geology. There is a triple scheme, a quadruple scheme, and schemes multiple according to the number of standards involved. Each standard gives rise to a different scheme.

The principle underlying the classification of natural phenomena is that different kinds of criteria give rise to different

taxonomic groups. The arrangement of rock-masses affords no exception to the rule. If the life phases be used as the predominant feature in delimiting the subdivisions of one order, prevailing lithologic character may be given greatest weight in another; physiography or specific biotic aspect in a third. Matters are greatly simplified by regarding the larger subdivisions of the geologic scale as essentially arbitrary, abstract time divisions, in which lithology has no place. With the smaller subdivisions, which are best considered as essentially structural divisions, the time element may be practically neglected.

While we have to allude to the time-interval, during which every rock-mass was formed, we have only universal structural units represented in the major two of the five taxonomic categories usually recognized. On the map, the expression of the time of formation of the terrane is by a distinctive color. The smaller of the universal time-units is thus represented. In like manner, only one of the rock categories becomes important on the map, and this is commonly represented by a standard pattern. This, too, is the smallest unit that is of broad geologic significance. While this plan does not always meet every case, it only needs slight adjustment from time to time in order to make it the most serviceable, the most practical, the most elastic, and most nearly in accord with local facts, of any scheme yet devised.

After all, the cartographic unit, like the species in zoology or botany, is necessarily a matter of convenience. In the exact delimitation of both, there enters very largely an element of personal judgment. Through the consensus of opinion we finally arrive at a tolerably good idea of what each unit should be.

It is commonly recognized that the principal criteria followed in delimiting the several taxonomic orders of units and in geological classification are (1) the relative progress of life in general as compared with that now existing; (2) the prevailing biotic type; (3) the general lithologic phase; (4) the specific lithologic character; and (5) the specific fossil feature.

Reference is here made to our most approved ideal classification because the lithologic individual fits closely into this scheme as the taxonomic subdivision of the fourth order. The

case of the St. Clair limestones of Arkansas, already referred to, and the formations of the Rico mountains, mentioned by Mr. Cross, are good examples in which strict lithologic separation was not obvious at first glance. In reality, Cross and Spencer's "Hermosa," "Rico," and "Dolores" formations approach definite geological formations only approximately. They represent no nearer the real geological formation than do purely lithologic individuals. Exact faunal studies in the Rico and neighboring districts are likely to require the divisional lines to be drawn at quite different horizons. When the fuller geological history of the region shall have been made out further rectification will doubtless be found necessary.

As a matter of fact, the lithologic individual based primarily upon lithology and secondarily upon fossils contained, and the "geological division" based upon the fossil characters have essentially the same kind of values as geological elements. But Mr. Cross, in his delimitations, does not depend entirely upon the faunal features, for he goes on to reënforce his statements by giving other reasons for drawing his lines where he does. Lithologic features are manifestly among the most important criteria in tracing the "formations." In the same way it is quite apparent that the advocates of strictly lithologic individuals in mapping do not and cannot depend wholly upon a uniform rock character.

This phase of the question leads to the statement of a more general one, that the main thing is to give clearer definition, than has usually been done, of each cartographic unit proposed. The unit should be defined according to (1) geographic distribution, (2) topographic expression, (3) lithologic nature, (4) stratigraphic delimitation, (5) biotic definition, and (6) mineral content.

When this shall have been done the foundation will have been laid for the establishment of real Geological Formations expressive of the geological history of the area mapped. The approximate "lithologic" map will not have to be materially changed, but only accompanied by a few words of additional explanation.

CHARLES R. KEYES.

THE MISNAMED INDIANA ANTICLINE.[1]

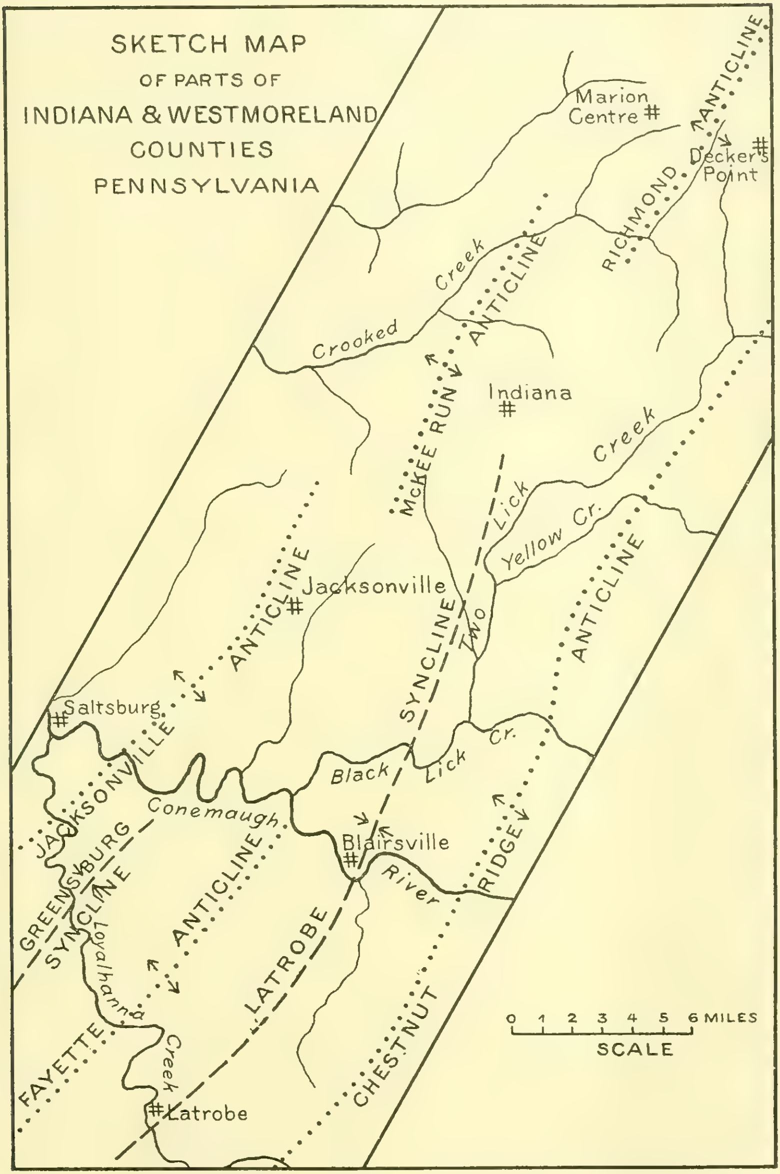
Recent work by the United States geological survey in western Pennsylvania has revealed a number of unsuspected facts of geologic structure. The results are being published in folios in which the lay of the rocks is shown by deformation contours, but it is thought desirable to call attention here to the finding of a syncline where formerly there was considered to be an anticline.

The map of Indiana county issued by the second geological survey of Pennsylvania shows the Indiana anticline to extend in a straight line through the town of Indiana. This supposed fold has been thought to be continuous on the southwest with the Fayette anticline in Westmoreland county and on the northeast with the anticline which is well marked near Richmond, on Little Mahoning Creek. The name Indiana anticline, therefore, has been applied to the entire fold. This term has passed into geologic literature and is still being used.

In the area adjacent to the type locality of the fold, however, the structure, as indicated by the accompanying sketch map, is quite different than previously interpreted. The Richmond and Fayette anticlines are not continuous, but the former pitches southwestward and the latter pitches northeastward, and the area between the Conemaugh River and Crooked Creek, along the extension of the axes of these folds is occupied by the Latrobe syncline. It is an odd coincidence that the axes of the Richmond and Fayette anticlines fall in line with each other, and it is not surprising that these folds have been thought to be continuous, for in the intervening region surface exposures are poor and the structure can be deciphered only by detailed work. The present determination is fully proved by the records of some fifty diamond drill holes lately put down by the Rochester and Pittsburg Coal and Iron Company.

Structural details will be published in the forthcoming Indiana

[1] Published by permission of the director of the United States geological survey.


SKETCH MAP
OF PARTS OF
INDIANA & WESTMORELAND
COUNTIES
PENNSYLVANIA
Marion Centre
Decker's Point
RICHMOND ANTICLINE
Crooked Creek
McKEE RUN ANTICLINE
Indiana
Creek
Lick
Yellow Cr.
ANTICLINE
Jacksonville
ANTICLINE
Two
SYNCLINE
Saltsburg
JACKSONVILLE
Black Lick Cr.
Conemaugh
Blairsville
River
GREENSBURG SYNCLINE
ANTICLINE
Loyalhanna
LATROBE
RIDGE
FAYETTE
Creek
CHESTNUT
Latrobe
0 1 2 3 4 5 6 MILES
SCALE

and Latrobe folios, so that only a few words need be added in explanation of the map. West of the Chestnut Ridge anticline the Latrobe syncline forms the northern extension of the Connellsville basin. This syncline rises and flattens out between Blairsville and Indiana, displacing the two westward succeeding folds. These folds are the Fayette anticline and the Greensburg syncline. Well developed where they cross Loyal Hanna Creek, northward in the vicinity of the Conemaugh River they fade away and merge into the western flank of the Latrobe syncline. The next fold to the west is the Jacksonville anticline, which has its maximum development near the town of Jacksonville. Southwest of Indiana there is an offset in the axis of this fold. Thence the arch continues northeastward, as the McKee Run anticline, and forms a low fold separated from the Chestnut Ridge anticline by the extension of the Latrobe syncline. Northeast of Indiana this syncline is divided in two by a south-plunging anticline, which, passing between Decker's Point and Marion Center, is well marked near the town of Richmond.

George B. Richardson.

Washington, D. C.

REVISED CLASSIFICATION OF THE UPPER PALEOZOIC FORMATIONS OF KANSAS.

CONTENTS.

INTRODUCTION.

IN 1895 the writer published a paper on "The Classification of the Upper Paleozoic Rocks of Central Kansas" in the JOURNAL OF GEOLOGY.[1] Additional field work and study of the Cottonwood Falls quadrangle render it advisable, in compliance with the custom of the United States Geological Survey to designate each lithologic individual capable of representation on the topographic map as a formation, to subdivide three of the units which were described as formations in that article.

A few changes in classification or nomenclature have been made which are also explained in this paper. Dr. J. W. Beede,

[1] Vol. III, pp. 682–706, and pp. 764–801.

of Indiana University, who has been associated with the writer in this later study, has rendered most efficient service in the field and other work necessary for this revision. Dr. George I. Adams, of the United States Geological Survey, spent several days with Dr. Beede in examining part of the area of the Cottonwood Falls quadrangle, and Mr. F. B. Weeks has also kindly furnished the author with references to the descriptions of formations from the United States Survey card catalogue of geologic formation names.

CLASSIFICATION.

WABAUNSEE STAGE.[1]

None but the upper rocks of this stage are exposed on the Cottonwood Falls quadrangle and the lower ones, exposed to the eastward, have not been carefully examined by the writer.

Burlingame limestone.—At the base of the Wabaunsee is a conspicuous and persistent limestone from seven to twelve feet in thickness, the lower limit of which is regarded as the lower line of that stage. It was named and briefly described by Hall in 1896[2] from outcrops near Burlingame and since then it has been traced from Nebraska across the state to Oklahoma.[3]

This limestone is frequently composed of two layers, gray to brown in color, separated by shale, and forms a massive ledge. This is apparently the division which was termed "limestone number 9" by Professors Haworth and Kirk, in 1894, exposed near the junction of the Cottonwood and Neosho rivers, which they stated "may be called the *Wyckoff limestone* . . . . on account of its great exposure in the vicinity of Wyckoff.[4]" This name, however, ought to be considered a synonym, for Dr. Sardeson had already given an almost identical one to a division of

[1] The word stage is used in the sense adopted by the International Congress of Geologists. See *Work Inter. Cong. Geologists*, 1886, p. 50; GILBERT, in *Proc. A. A. A. S.*, Vol. XXXVI, 1888, p. 186; Congrés Géologique International (8^{e} Session), *Procès-verbaux des Séances*, 1901, p. 35; and *ibid.*, *Comptes Rendus*, 1er Fasc., 1901, p. 196.

[2] *Univ. Geol. Surv. Kansas*, Vol. I, p. 105.

[3] See, "Map of Limestone Outcroppings," by PROFESSOR HAWORTH, Vol. III, *Univ. Geol. Surv. Kan.*, 1898, Pl. VII.

[4] *Kan. Univ. Quart.*, Vol. II, Jan. 1894, p. 111.

Permian system. (?)

Cimarron series

Big Blue series

(?)

[C]arboniferous system (upper part only).

Missourian Se[ries]
(Upper part of

CLASSIFICATION OF THE UPPER PALEOZOIC FORMATIONS OF KANSAS.

System	Series	Stage	Formation	Member
Permian system. (?)	Cimarron series[2] - Cragin, '96.	Kiger Stage[1] - Cragin, '96.	Taloga formation - Cragin, '97.	
			Day Creek dolomite - Cragin, '96.	
			Red Bluff formation - Cragin, '96.	
		Salt Fork Stage - Cragin, '96.	Dog Creek formation, Cragin, '96.	Chapman dolomite,[5] Cragin, '97.
				Amphitheatre dolomite, Cragin, '97.
			Cave Creek formation, Cragin, '96.	Shimer gypsum - Cragin, '96.
				Jenkins clay - Cragin, '96.
				Medicine Lodge gypsum, Cragin, '96.
			Glass Mountain formation, Cragin, '97.	Flower-pot shales - Cragin, '96.
				Cedar Hills sandstone, Cragin, '96.
			Kingfisher formation, Cragin, '97.	Salt Plain member - Cragin, '96.
				Harper sandstone[6] - Cragin, '96.
	Big Blue series[3] - Cragin, '96.	Summer Stage - Cragin, '96.	Wellington shales[7] - Cragin, '96.	
			Marion formation - Prosser, '95.	
		Chase Stage - Prosser, '95.	Winfield formation - Prosser, '97.	
			Doyle shales - Prosser and Beede.	
			Fort Riley limestone - Swallow, '66.	
			Florence flint - Prosser, '95.	
			Matfield shales - Prosser and Beede.	
			Wreford limestone - Hay, '93.	
(?) Carboniferous system (upper part only).	Missourian Series[4] - Keyes, '96. (Upper part of series)	Council Grove Stage.	Garrison formation, Prosser and Beede.	Neosho member - Prosser, '95.
				Florena shales, Prosser and Beede.
			Alma limestone - Prosser, '94.	
		Wabaunsee Stage - Prosser, '95.	Eskridge shales - Prosser and Beede.	
			Neva limestone - Prosser and Beede.	
			Elmdale formation - Prosser and Beede.	
			Americus limestone - Kirk, '96.	
			——— formation	
			Emporia limestone - Kirk, '96.	
			——— shales	
			Burlingame limestone - Hall, '96.	

1 The classification of the formations from the top of the Kiger to the Wellington shales, inclusive, is that of Dr. Cragin, except that he termed Kiger and Salt Fork *divisions* of the Cimarron series (*Col. Coll. Studies*, Vol. VI, March 27, 1896, pp. 3, 16–49). The following year Dr. Cragin revised the classification of the Cimarron series, changing the limits and names of some of the formations and drawing the line of separation between the Salt Fork and Kiger divisions at the *top* of the Dog Creek formation instead of at its *base*, as in the former classification (*Am. Geol.*, Vol. XIX, May, 1897, pp. 351–64).

2 *Col. Coll. Studies*, Vol. VI, pp. 3, 18, 48; and see additional account in *Am. Geol.* Vol. XIX, May, 1897, pp. 351–64.

3 *Col. Coll. Studies*, Vol. VI, March 27, 1896, pp. 3, 5, 6. In July, 1896, Dr. Keyes proposed "to recognize in the 'upper' Carboniferous of the Western Interior province three series having equal taxonomic rank," the upper one of which was named the "Oklahoman" (*Am. Geol.*, Vol. XVIII, p. 25). In defining the series it was stated that "In suggesting the name 'Oklahoman' as a serial geological term it is intended to apply to all those rocks of Carboniferous age which occur north of the Canadian river in Oklahoma, and which lie between the interval of the top of the Missourian series and the base of the Cretaceous. It may be regarded as essentially covering the same succession of strata that has long been vaguely known under the title of 'Permian.' The name is derived from the territory in which the formation has its best development and in which the most complete sequence is represented" (*ibid.*, p. 27). In October, 1891, Dr. Keyes recognized the Cimarron series and gave the Oklahoman and Cimarron as the two closing series of the Carboniferous (*Am. Jour. Sci.*, 4th ser., Vol. XII, pp. 306, 309), stating that "The so-called Permian of the Western Interior basin (Oklahoman and Cimarron, the latter generally known as the Red Beds) is composed largely of shales and shaly sandstones. . . . . The conditions existing were identical with those under which the original Permian beds of Russia were formed" (*ibid.*, p. 309). The following month Dr. Keyes published a "General Geological Section of the Carboniferous of the Mississippi Valley," in which a complete list of the series and terranes of the system is given. For the portion under consideration it is as follows:

	SERIES.	TERRANES.
Carboniferous system (upper portion).	Cimarron	Kiger shales.
		Salt Fork shales.
	Oklahoman	Wellington shales.
		Marion limestone.
		Chase limestone.
		Neosho shales.
	Missourian (upper part)	Cottonwood limestone.
		Atchison shales.

(*Am. Geol.* Vol. XXVIII, p. 302.) It will be seen that the Oklahoman series, as precisely defined above is identical with the Big Blue series proposed by Dr. Cragin in 1896, and therefore his name, which has priority, is adopted for this classification. In my revision the only change from Professor Cragin's classification of the Big Blue series is that the Neosho member at its base is put in the Missourian series. The Brazos series proposed by Prof. Hill in 1902 (*Twenty-first Ann. Rept. U. S. Geol. Surv.* Pt. VII, p. 100) for the Red Beds is apparently the same as the Cimarron series of Cragin.

4 "Missourian" was proposed as the name of a series by Dr. Keyes, in July, 1896 (*Am. Geol.*, Vol. XVIII, pp. 25–27). This was an outgrowth of the Missouri stage or formation which was proposed by him in 1893 (*Iowa Geol. Surv.*, Vol. I, pp. 85, 114; and *Mon. Rev. Iowa Weather Service*, Vol. IV, p. 3).

5 Nearly three years later Professor H. S. Williams gave the name "Chapman sandstone" to a formation occurring in northeastern Maine (*Am. Jour. Sci.*, 4th ser., March, 1900, Vol. IX, pp. 203, 205, which was more fully described in *Bull. U. S. Geol. Surv.*, No. 165, 1900, p. 78).

6 It is not probable that "Harper sandstone" can be retained for this subformation, because the very similar term of "Harper's shale" was published by Keith two years earlier as the name of a formation occurring near Harper's Ferry (*Geologic Atlas United States, Harpers Ferry folio* (Folio 10), 1894, pp. 3, 5).

7 The term "Wellington shales," apparently applied to this formation, first appeared in an article by Professor Cragin, in the Kansas City *Review of Science and Industry*, Vol. VIII, April, 1895, p. 679; and a little later he published it in the *Bull. Washburn College Laboratory of Natural History*, Vol. I, May (?), 1885, p. 86.

the Cincinnati series of the Ordovician in Minnesota, for which he proposed "a new name . . . . *Wykoff* beds — from the town near which the best exposure known occurs."[1] and this he later called the Wykoff formation.[2] The only difference is that the name of the Minnesota town is spelled without a *c*. In 1895 Professor Haworth proposed the name "Osage City shales" for the rocks included between the top of the Topeka limestone and the base of a thin limestone overlying the Osage coal; while about 150 feet of the superjacent rocks in the vicinity of Burlingame were named the Burlingame shales.[3] Later in the same year both divisions were more fully described by Professor Haworth;[4] but the upper limit of the Burlingame shale was not precisely defined. The following year Mr. Hall applied the term "Burlingame limestone" to eight feet of limestone which "covers the third and last heavy bed of shales in this section" with a thickness of 150 or 200 feet.[5]

This shale was apparently regarded by Mr. Hall as the Burlingame, since he used that name in the list of subjects at the beginning of his chapter,[6] and then the heading following that of the Burlingame limestone is the "Systems above the Burlingame shales."[7]

In 1898 Professor Haworth stated that "subsequent work has shown the unimportance of" the thin limestone overlying the Osage coal, "so that it will not do to depend upon it as a division line marker. Neither will the Osage coal serve such a purpose, as it is by no means continuous . . . . From these considerations it seems desirable to let the name Osage apply to the entire shale bed above the Topeka limestone and below the Burlingame limestone . . . This renders the name Burlingame shales superfluous and therefore it will be dropped."[8]

[1] *Bull. Minn. Acad. Nat. Sci.*, Vol. III, No. 3, 1891 (?), p. 326. It is stated by Professor N. H. Winchell and E. O. Ulrich that this paper was not distributed until April 9, 1892 (*Geol. Minn.*, Vol. III, Pt. I, of the final report, 1895, p. XLVI).

[2] *Am. Geol.*, Vol. XIX, Jan., 1897, p. 24; see also *ibid.*, May, 1897, pp. 332, 334.

[3] *Kan. Univ. Quart.*, Vol. III, April, 1895, p. 278.

[4] *Am. Jour. Sci.*, 3d ser., Vol. L, December, 1895, pp. 461, 462.

[5] *Univ. Geol. Surv. Kan.*, Vol. I, 1896, p. 105. [6] *Ibid.*, p. 99. [7] *Ibid.*, p. 105.

[8] *Ibid.*, Vol. III, p. 105; also see p. 73.

In 1898 Dr. Adams applied the name "Eureka limestone" to a formation exposed in the vicinity of that city,[1] which Professor Haworth correlated with the Burlingame limestone.[2] The name Eureka, however, was preoccupied, since Hague used it in 1883 for the Eureka quartzite of Nevada,[3] and later Dr. Branner named the Eureka shale of Arkansas.[4]

——— *shales.*— In Lyon county, succeeding the Burlingame limestone, according to Mr. Alva J. Smith, are nearly forty-five feet of blue to yellow shales and friable limestones, the latter comprising about eight feet of the total thickness of this formation, which is limited at the top by the Emporia blue limestone.[5] Dr. Adams has recognized as a formation the shales included between the Burlingame and Emporia limestones, which he has named in manuscript, and therefore no name is proposed for the division in this article.

Emporia limestone.— This division, as described by Mr. Smith, is composed of three feet of hard blue limestone at the base, the upper six-inch layer making a good flagstone, which is extensively used in Emporia. Then there is four feet of shale capped by another hard blue limestone two feet in thickness. These limestones "pass under the Cottonwood River at Soden's mill, one mile south of Emporia,"[6] and the Neosho River at the Rinker bridge. It was named by Kirk in 1896,[7] but, according to Mr. Smith, at some of the localities which he mentioned it was confused with a higher limestone. The blue Emporia limestone was correctly reported by Kirk in the "Chicago Mound" near Wyckoff; but the limestones near the "Emporia waterworks" and "along the hilltops about four miles south and one mile east of Emporia"[8] are higher and belong in what Mr. Smith named the "Emporia system."[9] The lower limestone

[1] *Ibid.*, p. 67. [2] *Ibid.*, p. 73. [3] *Third Ann. Rept. U. S. Geol. Surv.*, pp. 253, 262.

[4] *Ann. Rept. Geol. Surv. Ark.*, for 1888, Vol. IV, 1891, p. 13, and see description by Professor Simonds on p. 26.

[5] See *A Bulletin on Lyon County Geol.*, 1902, pp. 2, 10; and *Trans. Kan. Acad. Science*, Vol. XVII, 1901, p. 193.

[6] *Bull. Lyon County Geol.*, pp. 2, 10; and *Kan. Acad. Sci.*, Vol. XVII, p. 193.

[7] *Univ. Geol. Surv. Kan.*, Vol. I, p. 80. [8] *Ibid.*, p. 82.

[9] Letter of Mr. Smith, Jan. 20, 1902. For a description of the Emporia system see *Bull. Lyon County Geol.*, p. 3.

was called the "Emporia blue" by Mr. Smith,[1] who states that it is much more uniform than the upper, and that he has traced it across Lyon county. He also identified it two miles east of Harveyville, in Wabaunsee county, and four miles northwest of Eureka, in Greenwood county. It appears to be a persistent limestone for some considerable distance, which can be traced and mapped, and is, therefore, probably entitled to rank as a sub-stage of the Wabaunsee.

——— *formation.*— Above the Emporia limestone, as described by Mr. Smith, is a zone nearly seventy feet thick, composed mainly of shale, but with a foot of limestone and a five-inch stratum of coal in the lower part, and a five-foot sandstone near the top. Then comes a zone composed of five limestone strata from one to two feet in thickness, separated by shales from four to ten feet thick, and with a total thickness of twenty-four feet. Mr. Smith named this zone the Emporia system,[2] and has represented its distribution three-fourths of the distance across Lyon county.[3] He writes me, however, that "the five limestones which I have included in the Emporia system are not very persistent, and the character and thickness of the stone, as well as the intervening shale, are subject to sudden changes. I have been unable to identify it beyond the lines of this county."[4] It hardly appears desirable to regard this zone as entitled to the rank of a formation. Then, according to the measurements of Mr. Smith, there are 210 feet of rocks composed largely of sandy shales, but also containing some thin beds of limestone, coal, and sandstone. The most important coal stratum is ten inches in thickness, and it occurs 75½ feet above the base of this member. So far as I am able to judge, it would appear advisable to put these three members in one formation, giving it a thickness of about three hundred feet. Dr. Adams ranked the rocks included between the Emporia and Americus limestones as a formation, which he has named in manuscript, and, therefore, no name is proposed for this formation.

[1] *Ibid.*, p. 2. [2] *Bull. Lyon County Geol.*, 1902, p. 3.

[3] *Trans. Kan. Acad. Sci.*, Vol. XVII, 1901, p. 191; and *Bull. Lyon County Geol.*, p. 8.

[4] Letter of January 20, 1902.

Americus limestone.— This name was given by Kirk in 1896 to two thin layers of limestone, separated by shale, which are quarried near Americus.[1] It was also noted by Haworth and Kirk in their "Neosho river section" and called "limestone system No. 11."[2] The lower stratum is buff in color, very solid and compact, making a good building stone with a thickness of twenty-one inches, according to Smith. Then comes six feet of shale with a six-inch flag limestone on top,[3] making a total thickness of over eight feet, and its distribution has been mapped entirely across Lyon county by Smith.[4] On the Cottonwood Falls quadrangle it is probable that this limestone is only a few feet below water in the Cottonwood River east of Elmdale.

Elmdale formation.— This formation, the succeeding ten and the lower and middle parts of the Marion, are represented on the Cottonwood Falls quadrangle, which has also furnished the majority of the names, and consequently these have been more thoroughly studied by the writer than the preceding formations. It is about 130 feet in thickness, and composed of yellowish to bluish shales, with thin beds of grayish alternating limestone, including two or three thicker ones. About thirty feet above the base of the formation is a friable limestone with a thickness in some localities of four feet, which is composed to a large extent of the tests of *Fusulina secalica* Say. This stratum weathers readily and leaves great numbers of *Fusulina* in the soil. About thirty-five feet higher is another conspicuous yellowish limestone, the center of which weathers to a rough face, and from ten to fifteen feet below the top is a limestone stratum from three to five feet in thickness. The formation is limited at the base by the top of the Americus limestone, and at its top by the base of the massive Neva limestone. It is well exposed on the bluff east of Elmdale, from which town it is named.

[1] *Univ. Geol. Surv. Kan.*, Vol. I, pp. 80, 81.

[2] *Kan. Univ. Quart.*, Vol. II, January, 1894, p. 111.

[3] *Bull. Lyon County Geol.*, pp. 3, 10.

[4] *Trans. Kan. Acad. Sci.*, Vol. XVII, 1891, p. 191; and *Bull. Lyon County Geol.*, p. 8.

Neva limestone.— This formation consists of a massive bluish-gray limestone or of a lower and upper massive limestone, each one a little over four feet in thickness, separated by two feet of shales, with a total thickness of about ten feet. The limestone, forming frequent ledges seven feet or more in thickness, breaks off in large blocks with sharp angles and a rough, jagged surface, weathering to a color not dissimilar to that of bleached bones. It was noted by Swallow in 1866[1] and represents the upper stratum of Haworth and Kirk's "limestone system No. 12,"[2] to which "system" Kirk later apparently applied the name "Dunlap limestone."[3] The limestone is finely exposed in the anticlinal fold to the northeast of Neva, a station on the Atchison, Topeka & Santa Fe railroad near the junction of the Diamond Creek and Cottonwood River valleys, hence its name.

Eskridge shales.— Between the Neva and the next higher massive limestone is a mass of shales, with perhaps some thin limestone layers, varying from thirty to forty feet in thickness. The shales are of greenish, chocolate, and yellowish color, and usually form covered slopes between the two conspicuous limiting limestones. They form the upper division of the Wabaunsee stage, and are named from the exposures in the vicinity of Eskridge, Wabaunsee county.

COUNCIL GROVE STAGE.

In my original description of these formations the line of separation between the Upper Coal-measures and Permian was doubtfully drawn between the Cottonwood and Neosho formations;[4] while the Permian appeared as a series of the Carboniferous, in accordance with the usage of the United States Geological Survey.[5] Since then Dr. Frech has reviewed this classification and drawn the lower line of the lower Dyas (Permian) at the base of the Chase stage, while it is stated that the Neosho is a transition to the Carboniferous, and a distinct line fails.[6]

[1] *Prelim. Rept. Geol. Surv. Kan.*, p. 16, Nos. 82–4.

[2] *Kan. Univ. Quart.*, Vol. II, 1894, p. 112.

[3] *Univ. Geol. Surv. Kan.*, Vol. I, 1896, p. 81.

[4] JOUR. GEOL., Vol. III, 1895, p. 800.

[5] See *Ibid.*, p. 796, f. n. [6] *Lethaea palaeozoica*, Bd. II, 2 Lief., 1899, p. 378.

On the chart showing the partial distribution of the Carboniferous, the Chase is apparently given as corresponding to the lower part of the Arta stage, which, according to his classification, is the oldest stage of the Permian, and the Neosho is represented as about on the dividing line between the Permian and Upper Carboniferous, although perhaps it is intended to include all of it in the latter division.[1] It is stated, however, that the older Chase and Neosho strata (as compared with the Marion) beyond doubt can only correspond to the Artinsk stage (which is the oldest Permian of Russia=Arta stage), and that a sharper division is made impossible by the absence of Cephalopods.[2] It is to be noted that in the latter part of this work devoted to "Die Dyas," in the table of Kansas Dyassic formations, Dr. Frech has left the Neosho as the oldest division of the Palæo-Dyas. In this case, however, he was reporting the classification of Professor Cragin, for it is stated that in the following table the Kansas strata are enumerated according to a recent survey, and it is not thought that he intended to set aside his earlier correlation.[3]

In reference to the correlation of these divisions the writer has stated that "The appearance and the prominence of the *Pseudomonotis* fauna in the Neosho formation furnishes a strong reason on the biologic side" for its correlation with the Permian.[4] The presence of *Pseudomonotis* is no longer an important argument in favor of putting the Neosho in the Permian, because since then Dr. Beede has identified *Pseudomonotis Hawni*, and described a new variety of that species and two new species from the older formations of the Upper Coal-measures of Kansas.[5]

There is a marked lithologic change at the base of the Chase stage where it begins with the Wreford limestone, which is the lowest one of the very cherty massive limestones. It is perhaps

[1] *Ibid.*, "Tab. XXIV, Einige wichtige Vorkommen des Carbon."

[2] *Ibid.*, p. 377, f. n.: "Dass die tieferen Chase-und Neosho-Schichten nur der Artinskischen Stufe entsprechen können, steht ausser Zweifel; jedoch wird eine schärfere Abgrenzung durch das Fehlen der Cephalopoden unmöglich gemacht."

[3] *Ibid.*, 3 Lief., 1901, p. 514.

[4] JOUR. GEOL., Vol. III, 1895, p. 796.

[5] *Kan. Univ. Quart.*, Vol. VIII, April, 1899, Ser. A., pp. 79–84; and *Univ. Geol. Surv.*, Vol. VI, 1900, pp. 132–35.

a more satisfactory classification to regard the base of the Permian as marked by the lower limit of the Wreford limestone and the writer is inclined to accept this line for the division as indicated by Dr. Frech. If this be done the writer would class the two formations succeeding the Eskridge shales (Cottonwood limestone and Garrison) together to form a stage for which he would propose the name of Council Grove. The upper part of the stage is well shown in the bluffs of the Neosho River and its tributaries in the immediate vicinity of this city, while the Cottonwood limestone and the overlying Florena shales may be found in the Neosho valley, about six miles below Council Grove.

Alma limestone.—This is a massive light gray to buff-colored, foraminiferal limestone, frequently composed of two layers with a thickness of about six feet. It contains very few fossils, with the exception of *Fusulina secalica* Say, which is extremely abundant in its upper part, and is called "wild rice" by the quarrymen. It is the most important dimension stone in Kansas, and at various localities are extensive quarries. Its constant lithologic character, with its line of outcrop frequently marked by a row of massive light gray rectangular blocks filled with *Fusulina*, make it one of the most important stratigraphic horizons in the Upper Paleozoic rocks for at least two-thirds of the distance across Kansas and into Nebraska. Swallow called the stratum the Fusulina limestone,[1] and for years it has been known commercially as the Cottonwood or Cottonwood Falls limestone, and at other localities as the Alma and Manhattan limestone. Haworth and Kirk, in their "Neosho River section," called it "limestone system No. 13, which is considered the equivalent of the famous Cottonwood Falls limestone;"[2] but in their description of the quarries near Cottonwood Falls, under their "Cottonwood River section," simply called it "No. 13,"[3] and did not apply to it the term Cottonwood Falls limestone. The same year Prosser proposed the name "Cottonwood formation" for the limestone and superjacent fossiliferous

[1] *Prelim. Rept. Geol. Surv. Kan.*, 1866, p. 16.

[2] *Kan. Univ. Quart.*, Vol. II, Jan. 1894, p. 112. [3] *Ibia.*, p. 113.

shales, on account of the excellent outcrops of both in the bluffs bordering the Cottonwood River below and above Cottonwood Falls and Strong. The lower division was named the "Cottonwood limestone" and the upper the "Cottonwood shales,"[1] while the same limestone quarried in the vicinity of Alma was mentioned locally as the "Alma massive limestone."[2] The following year the formation and its two members were more fully described by Prosser.[3] The name "Cottonwood," however, was apparently used for a geological division by N. F. Drake as early as September, 1893, when he described the "Cottonwood Creek bed" of the Texas Carboniferous.[4] It is now proposed to limit the formation to the Cottonwood limestone and on account of the prior use of the name Cottonwood for the Texan bed, to call it the Alma limestone from the outcrops near the town of that name in Wabaunsee county, while the Cottonwood shales are referred to the succeeding formation.

Garrison formation.—This formation is composed of two members, the yellowish fossiliferous shales at the base, formerly called the Cottonwood shales, and the upper one, composed of the alternating gray limestones and various colored shales called the Neosho, with a total thickness of from 140 to 145 feet. The lower shales have a thickness of thirteen feet near Strong, but decrease to two or three feet in the northern part of the state. The lower part of these shales contains immense numbers of a few species of fossils and on this account may be readily identified wherever outcrops occur. Since the geographic name "Cottonwood" is preoccupied the term "Cottonwood shale" is abandoned, and they are renamed the Florena shales from the exposures over the Alma limestone in the quarries near Floren, in the Big Blue valley.

The upper member of the formation is composed of green, chocolate, and yellowish shales alternating with grayish limestones, while in the Big Blue valley a bed of gypsum occurs near the base. Certain layers of the coarser shales and limestones

[1] *Bull. Geol. Soc. Amer.*, Vol. VI, Nov. 1894, p. 40. [2] *Ibid.*, p. 44.

[3] Jour. Geol., Vol. III, Oct. 1895, pp. 697–705.

[4] *Fourth Ann. Rept. Geol. Surv. Texas*, pp. 374, 382.

contain an abundant Lamellibranch fauna, and the entire fauna is thought to be a mixture of species found in the western Coal-measures, together with others occurring in the division generally termed the Permian or the Permo-Carboniferous. This member was originally termed the Neosho formation from the excellent outcrops in the Neosho valley near Council Grove.[1] The Florena shales and Neosho member are now united to form the Garrison formation, so named on account of the good exposures from Garrison south in the Big Blue valley.

CHASE STAGE.

As in the case of the Wabaunsee, it has been found advisable for mapping to divide this stage, which was formerly called the Chase formation, into several formations, which are described in ascending order. These subdivisions of the Wabaunsee and Chase stages are sufficiently definite lithologic divisions to be traced across the Cottonwood Falls quadrangle, and some distance to the north and south, and therefore can be mapped. It does not appear to the writer, however, that these divisions are entitled to the rank of a stage, and he would term them substages. If we consider the well-known Hamilton division a stage of the New York Devonian, then it would appear that these divisions correspond more nearly to the Moscow shales, Encrinal limestone, Ludlowville shales, and other subdivisions of that stage, than to the entire Hamilton.

Wreford limestone.—This formation is composed of limestone and chert, or flint as it is popularly termed throughout the Flint Hills region, and varies in thickness from thirty-five to fifty feet. In general it is composed of three strata, a cherty limestone below and above, separated by a heavy limestone nearly free from chert. The rock is buff in color, often weathering much lighter, and forms the first conspicuous flint terrace above the Alma limestone. It is quite extensively quarried and used for construction stone or crushed for railroad ballast. It was called the Strong flint in 1895,[2] but is now known to be the equivalent of the Wreford limestone, which was named by

[1] JOUR. GEOL., Vol. III, 1895, p. 764. [2] JOUR. GEOL., Vol. III, p. 773.

Professor Hay in 1893 from exposures near Wreford, Geary county, south of Junction.[1] The preceding report of the State Board contained the same table of Professor Hay's "Fort Riley section," except that this division was called the "Walford limestone," which was undoubtedly a typographical error for Wreford.[2]

Matfield shales.—The formation is composed principally of variously colored shales, with some shaly buff, occasionally cherty limestones, and a light gray limestone two feet or so in thickness, which occurs about thirty feet below its top. The thickness ranges from sixty to seventy feet, and it generally forms covered slopes between two massive and conspicuous flint ledges. It is named from Matfield township, Chase county, where it forms the side of the steep escarpment above the Wreford limestone.

Florence flint.—This formation is about twenty feet in thickness and consists of very cherty limestone separated by definite layers of chert, with a band of shaly or white cellular limestone near the center. It is excellently exposed on the McPherson branch of the Atchison, Topeka & Santa Fé Railroad, and in the Jones quarries along that railroad, from one to two miles northeast of Florence, and on this account in 1895 it was named the "Florence flint."[3]

Fort Riley limestone.— Overlying the Florence flint is a series of massive buff limestones, changing to thin bedded and shaly strata in the upper part of the formation, which have a total thickness of forty feet or more. Near the center of the formation are generally one or two massive layers, which on the weathered surface form a conspicuous ledge that may be readily followed by the eye for miles on the bluffs of the Cottonwood and Kansas rivers. Swallow in 1866 applied the term "Fort Riley limestone" to the massive ledge in the vicinity of Fort Riley, which he described as "a buff porous magnesian rock, in thick beds," with a thickness of from eight to ten feet.[4] This

[1] *Eighth Bien. Rept. Kan. State Board Agri.*, Part II, p. 104.

[2] *Seventh ibid.*, 1891, Part II, p. 94.

[3] JOUR. GEOL., Vol. III, p. 773.

[4] *Prel. Rept. Geol. Surv. Kansas*, p. 14.

name is now adopted for this formation, but its limits are extended to include the thinner bedded limestones both below and above the massive Fort Riley main ledge. The Florence limestone[1] is apparently equivalent to the Fort Riley main ledge and the name is now abandoned.

Doyle shales.—This formation is composed of variously colored shales with an occasional thin stratum of soft limestone, and has a thickness of sixty feet. About twenty feet above the base is a thin, grayish limestone which often appears on the surface, and at the top are yellowish shales containing a few fossils. These shales and the rocks of the overlying formations weather easily and form gently undulating prairies in sharp contrast with the rough topography produced by the flint and massive limestones below. The formation is shown at various places in the Doyle Creek valley to the southwest of Florence, from which locality it is named the Doyle shales.

Winfield formation.—This has a thickness of about twenty-five feet, and is composed of a cherty limestone at the base with a massive concretionary one at the top, the two separated by yellowish shales. This chert and concretionary limestone form the highest prominent chert ledge in the Kansas Permian, and make a marked stratigraphic horizon that is of great assistance in determining the areal geology of eastern central Kansas. The chert is not so uniform in occurrence as in the Wreford and Florence flints, and at some localities this horizon is represented simply by a prominent light gray limestone, nearly free from chert. The concretions in the upper limestone are quite persistent through long stretches of outcrop, although occasionally areas are found where they are small and inconspicuous or absent. As a rule, however, they are large, and the stratum may readily be traced across the country either from its exposure in bluffs or streams or from the line of loose reddish-brown concretions stretching across the prairie. The irregular worn upper surface of the concretionary limestone and the appearance of many of the concretions, as though rolled in the mud on the sea bottom, indicate a shallowing of the sea at this time, fol-

[1] JOUR. GEOL., Vol. III, 1895, p. 773, No. 15 of the Chase section.

owed by a subsidence of the sea bottom before the deposition of the succeeding even thin bedded limestones. This change of physical condition is indicated in the fauna by the nearly complete disappearance of the brachiopods and the survival of a fauna composed mainly of Permian lamellibranchs. This formation constitutes the upper division of the Chase stage, and in the preliminary description of these rocks it was called the "Marion flint and concretionary limestone"[1] from the outcrops below Marion, and regarded as a subformation. The overlying buff limestone and shales, however, were named the Marion formation and hence to avoid confusion the name Marion was dropped for the lower division and it was renamed the Winfield concretionary limestone from the outcrops in the vicinity of Winfield, Cowley county, in southern Kansas.[2] Fourteen months later Dr. Keyes published the name "Winfield limestone," which he applied to a Cambrian formation found in the Mississippi valley near Winfield, Lincoln county, Missouri.[3] In 1900 Professor Harris and Mr. Veatch applied the very similar name of Winnfield limestone (spelled Winn) to a Cretaceous formation of northern Louisiana.[4] Clearly the Kansas usage of the name has priority, and Winfield is adopted as the name of this formation.

SUMNER STAGE.

The two upper formations of the Big Blue series (the Marion and Wellington shales) were classed together by Professor Cragin to form the Sumner division.[5] It was named after Sumner county in southern Kansas which includes nearly the entire breadth of its outcrop in that part of the state. This name is retained for this division, which is considered to have the rank of a stage.

Marion formation.—Buff thin-bedded limestones and shales form the principal part of this formation which is the latest Paleozoic one found on the Cottonwood Falls quadrangle. The

[1] JOUR. GEOL., Vol. III, 1895, p. 772.

[2] *Univ. Geol. Surv. Kan.*, Vol. II, Feb. 15, 1897, p. 64.

[3] *Proc. Iowa Acad. Sci.*, Vol. V, April 28, 1898, p. 60.

[4] *Geol. Surv. La.*, Report for 1899, Sec. II, p. 56.

[5] *Col. Coll. Studies*, Vol. VI, pp. 3, 9, 48.

lower part is composed of rather soft, porous, thin-bedded limestones and shaly layers to shales, containing near the base a considerable number of silicious geodes and occasionally some chert. Some fifty or sixty feet above the base is a buff limestone containing large numbers of small lamellibranchs, as *Pleurophorus subcuneatus* M. & H., *Bakewellia parva* M. & H., *Yoldia subscitula* M. & H., and other species, while about twenty feet higher is another similar limestone containing large lamellibranchs, as *Aviculopecten occidentalis* (Shum) Meek, *Myalina permiana* (Swallow) M. & H., and *Pseudomonotis Hawni* (M. & H.). A limestone containing *Pleurophorus* occurs in some localities near this horizon, which also contains large chert concretions.

The upper portion of the formation is composed mostly of thin buff limestones similar to those in the lower portion, alternating with a greater thickness of shales and marls, and in some localities contains beds of gypsum and salt. On Turkey Creek, south of the Smoky Hill valley and Abilene, a conglomerate stratum from fifteen to twenty feet in thickness occurs some 150 feet above the base of the formation, which was first described by Meek and Hayden in 1859.[1] To the northwest of the Cottonwood Falls quadrangle two beds of gypsum occur in this formation in Dickinson and Saline counties, both of which are worked. The lower one was named the "Solomon gypsum" by Dr. Grimsley,[2] and various outcrops occur up Gypsum Creek to Gypsum, as well as on Holland Creek, near Dillon. The higher bed is found in Greeley township, southeast of Salina, which was called the "Greeley gypsum" by Dr. Cragin,[3] while at Hope in the southeastern part of Dickinson county both strata of gypsum occur, separated by one hundred feet of shales and limestones. In southern central Kansas there are indications of a third horizon, forty feet above the Greeley gypsum, while the deposit in the southern part of the state, about four miles northwest of Geuda Springs, Sumner county, is in the upper part of the forma-

[1] *Proc. Acad. Nat. Sci. Philadelphia*, Vol. IX, p. 16, No. 9.

[2] *Univ. Geol. Surv. Kan.*, Vol. V, 1899, p. 61.

[3] *Col. Coll. Studies*, Vol. VI, 1896, p. 10.

tion.[1] In the southern part of the state the upper portion of the formation consists to a large extent of clay-shales of various colors, with some beds of limestone, gypsum, and rock salt. Its lithologic character, as it dips deeply below the surface to the westward, is shown by the well records to change from the variegated shales alternating with beds of limestone and gypsum to saliferous shales of bluish-gray to slate color alternating with massive beds of rock salt. It covers a large portion of the eastern two-thirds of Marion county, its lower part is quite well shown in the vicinity of the city of Marion, and for these reasons it was given the name "Marion formation."[2] On account of the terms "Marion flint" and "Marion concretionary limestone," Professor Cragin, in 1896, named this formation the "Geuda Salt-measures," from Geuda, Sumner county,[3] which name he withdrew during that year in favor of the "Marion formation."[4]

Wellington shales.—This formation consists largely of bluish-gray to slate-colored shales, but contains some red ones, and in the southern part of the state beds of impure limestone and calcareous shales, together with occasional beds of gypsum and dolomite. Limited saline deposits are reported, but no rock salt. Fossils are very rare, and, as far as the writer is informed, none have been found in the formation. In the Smoky Hill valley there are about two hundred feet of the Wellington shales, but they thicken to the south, and are reported as 450 feet in thickness in Sumner county, near the southern line of the state. Professor Cragin named and described these shales in 1896 from exposures in the vicinity of Wellington, the county seat of Sumner county.[5]

TABLE OF THE UPPER PALEOZOIC FORMATIONS OF KANSAS.

The formations just described, together with the succeeding ones of the Permian, have been arranged in the following table of the Upper Paleozoic formations of Kansas.

[1] See DR. GRIMSLEY'S account in *Univ. Geol. Surv. Kan.*, Vol. V, 1899, p. 69.

[2] JOUR. GEOL., Vol. III, 1895, p. 786.

[3] *Col. Coll. Studies*, Vol. VI, March, 1896, pp. 3, 9–16.

[4] *Am. Geol.*, Vol. XVIII, Aug., 1896, p. 132.

[5] *Col. Coll. Studies*, Vol. VI, pp. 3, 16.

CORRELATION OF THE CIMARRON SERIES.

In the earlier papers of the writer, the Cimarron series was referred provisionally to the Permian[1]; but later the discovery of Permian fossils as high as the Red Bluff formation, together with other data, apparently proves that at least the greater part of the series is of Permian age. Most of the fossils have been found by Professors A. H. Van Vleet and Charles N. Gould; the latter has described the horizons from which they were collected and given a list of three specific and three generic identifications of Permian vertebrates by Dr. Williston, which came from near the base of the Harper sandstone, and eleven genera of invertebrates identified by Dr. J. W. Beede. He states that the highest locality, which is in the Red Bluff formation, "has yielded some twenty species of invertebrates, several of which are of new forms."[2]

Dr. Beede, who has also published a note concerning these highest fossils, states that "they are mainly pelecypods with a species of brachiopod and a few gasteropods. . . . *Aviculopecten occidentalis* (Shum) Meek, is also present, and one other species bearing somewhat of a resemblance to it, but quite different from it in some respects, is also present. One of the common fossils is a biplicate terebratuloid, *Dielasma Schucherti* Beede, belonging to a group of this genus heretofore unknown in the American Permian. Mr. Schuchert informs me that it is very similar to a species of this genus described by Waagen from the Permian of Europe. . . . .

The presence of these fossils clearly demonstrates the Permian age of these rocks, coming as they do from very near to the top of the beds."[3] The description of these invertebrate fossils from the Red Beds by Dr. Beede has been published as an Advance Bulletin of the First Biennial Report of the Oklahoma Geological Survey.[4] The following new species are

[1] *Univ. Geol. Surv. Kansas*, Vol. II, 1897, pp. 89–92; *Kan. Univ. Quart.*, Vol. VI, 1897, pp. 150, 151; JOUR. GEOL., Vol. VII, 1899, pp. 354–6.

[2] JOUR. GEOL., Vol. IX, July, 1901, p. 339.

[3] *Am. Geol.*, Vol. XXVIII, July, 1901, pp. 46, 47.

[4] April, 1902, pp. 1–11, with one plate.

described: *Bakewellia Gouldii*, *Conocardium oklahomaensis*, *Aviculopecten Van Vleeti* and *Dielasma Schucherti*; *Aviculopecten occidentalis* is identified and, generically, specimens of *Naticopsis*, *Pleurotomaria*, *Schizodus*, *Lima* and *Pleurophorus*, all of which are from White Horse Springs, Oklahoma. Dr. G. I. Adams also states that Dr. Williston considers the vertebrate remains from the Harper sandstone "as equivalent to Cope's Lower Permian fauna from the Wichita beds of Cummins in northern Texas."[1] He further said, in discussing the age of the Red Beds of eastern Oklahoma, that "The age of that portion of the Red Beds which is in strike with the Permian of Kansas may confidently be expected to be found to be of Permian age. This is in accordance with the evidence already furnished by the vertebrate fossils. Above the Permian limestones in Kansas occur the Wellington shales, which are bluish and greenish-gray in color. They are probably represented southwestward by formations which are red. The succeeding formations are typical Red Beds, and have thus far yielded only Permian fossils."[2]

In a discussion of the "Relations of 'Upper Permian' to Triassic" Dr. Keyes has stated that "Prosser has been led to believe that the greater part of the Kansas 'Red Beds' are Triassic."[3] The above statement is erroneous, for previous to the publication of Dr. Keyes' paper my discussion of the Cimarron series in the Kansas report appeared under the heading of "The Upper Permian." At that time, however, I did not consider the evidence strong enough to justify their correlation with the Permian without a question.[4] This idea was expressed near the close of the section on "Correlation" in the following sentence: "On account of this dissimilarity in lithologic characters [between the Red Beds of Texas and Kansas] and the absence of fossils in Kansas and northern Oklahoma, together with the fact that there is yet no account of the careful tracing of any part of the Red-Beds across Oklahoma to Texas where their age

[1] *Am. Jour. Sci.*, 4th ser., Vol. XII, Nov., 1901, p. 383.

[2] *Ibid.*, p. 386.

[3] Jour. Geol., Vol. VII, July, 1899, p. 339.

[4] See the table of classification in *Univ. Geol. Surv. Kansas*, Vol. II, Feb., 1897, p. 94.

could be determined by comparison with the fossiliferous terranes, the correlation of these rocks with either the Triassic or Permian is a matter of uncertainty."[1] In the later paper of that year I simply quoted the opinions of Dr. Williston, Professor Grimsley and Mr. Vaughan, without expressing any opinion, beyond the statement that "there is uncertainty as to their age,"[2] while in my paper succeeding that of Dr. Keyes' in the same number of the JOURNAL OF GEOLOGY it was stated that "The Paleozoic of Kansas closes with the Cimarron group or the Red Beds;"[3] following which was an account of the identification by Dr. Williston of *Eryops megacephalus* from the lower part of the Cimarron series, an amphibian described by Cope in the Permian of Texas.

THE PERMIAN QUESTION.

CORRELATION OF THE UPPER PALEOZOIC OF KANSAS WITH THE RUSSIAN PERMIAN.

Opinions of various geologists.—There is still a difference of opinion among American geologists in regard to the correlation of the Upper Paleozoic formations of Kansas with the Russian Permian. The JOURNAL OF GEOLOGY published in 1898, "A symposium on the classification and nomenclature of geologic time-divisions," in which Dr. Williston,[4] Professor Calvin[5] and Dr. Keyes[6] reported adversely both as to the identification of the Permian in Kansas and to its recognition as a period coördinate with the Carboniferous or Devonian; while Dr. William B. Clark stated that for the later divisions of the Paleozoic he should employ the chronologic terms Carboniferous and Permian.[7] Dr. Clark wrote me later as follows regarding this subject:

> I distinctly object to the abandonment of the term Permian for a major division and can see no just grounds for it since the division is one of importance in Europe and other portions of the world. To be sure, in America the Permian conditions are not as prominent, but I can see no reason on that ground for disturbing the geological column as it has come to be generally accepted.[8]

[1] *Ibid.*, p. 92. [2] *Kan. Univ. Quart.*, Vol. VI, Dec. (?), 1897, p. 150.

[3] *Loc. cit.*, Vol. VII, p. 354. [5] *Loc. cit.*, p. 353. [7] *Loc. cit.*, p. 341.

[4] *Loc. cit.*, Vol. VI, p. 343. [6] *Loc. cit.*, p. 352. [8] Letter of December 16, 1898.

Vertebrate fossils found in northern Texas led Professor E. D. Cope to the conclusion that the rocks were of Permian age and he stated that "The evidence now adduced is sufficient to assign the formation, as represented in Illinois and Texas, to the Permian."[1] The invertebrate fossils from the same beds were regarded by Dr. Charles A. White as indicating their Permian age.[2] The stratigraphy of the Upper Paleozoic formations of Texas was fully described by Professor W. F. Cummins, who referred them to the Permian.[3]

In recent years the following geologists have studied the Upper Paleozoic rocks of Oklahoma, Kansas or Nebraska and termed them Permian. Dr. James P. Smith who stated that "The lower Permo-Carboniferous strata of Kansas and Nebraska are probably also to be correlated with the Artinsk stage [basal Permian of Russia]."[4] Professor Cragin, who gave an extended account of "the Permian system in Kansas;"[5] Professor Wilbur C. Knight who wrote a similar paper on "The Nebraska Permian"[6] and showed from tables of distribution that "Of the forty-four genera of invertebrates known in the Kansas and Nebraska rocks, over three-fourths of them belong to the Permian of the Orient. The remainder are nearly all American genera and are chiefly pelecypods."[7] Prof. Knight has also stated that "From our present knowledge it seems advisable to refer the Red Beds of the Laramie Plains [Wyoming] to the Permian."[8] Dr. J. W. Beede, in his paper on "A Reconnaissance in the Blue Valley Permian"[9] described the Lower Permian as represented in Kansas north of the Kansas river and in southern Nebraska. And finally Professor Charles N. Gould and Doctor

[1] *Geol. Surv. Texas, Second Ann. Rept.*, 1891, p. 414.

[2] *Bull. U. S. Geol. Surv.*, No. 77, 1891.

[3] *Geol. Surv. Texas, Fourth Ann. Rept.*, 1893, p. 212.

[4] JOUR. GEOL., Vol, II, 1894, p. 194; and see pp. 188, 204. Also see *Proc. Am. Phil. Soc.*, Vol. XXXV, 1896, reprint pp. 11, 12, 24.

[5] *Col. Coll. Studies*, Vol. VI, 1896, pp. 1–49 and supplemented by one in the *Am. Geol.*, Vol. XIX, 1897, pp. 351–64.

[6] JOUR. GEOL., Vol. VII, 1899, pp. 357–75.

[7] *Ibid.*, p. 370. [8] JOUR. GEOL., Vol. X, 1902, p. 421.

[9] *Kan. Univ. Quart.*, Vol. IX, July, 1900 (1901), pp. 191–203.

Beede have shown from fossils, the Permian age of the Kansas-Oklahoma Red Beds.[1]

Another paleontologist, who is studying the fossils of the western Carboniferous writes me :

I don't believe that there is any Permian there at all, unless possibly the Marion and superjacent beds are Permian. I express the opinion with that qualification, (the possibility of the Marion being Permian), and another that the Kansas area *may* have been a shut-in basin and have retained its Carboniferous facies into Permian time.

Dr. Erasmas Haworth wrote me as follows:

I do not hesitate to say that I am most strongly opposed to the substitution of the term Oklahoman or any other for that of Permian. It looks now as though the whole of the Red Beds would be called Permian. Should this be done we will have a terrane which, along the southern line of Kansas, will be from 2,000 to 3,000 feet thick, or in other words as thick as the whole of the Coal-measures. This mass of earth is as different in all physical aspects from the Coal-measures as they are from any other terrane. It should be given a prominent place, but just how prominent I am not yet ready to express an opinion. I do not see how anybody can well settle the question of rank of the American Permian until all these questions are worked out, which work will necessitate an intimate examination of the territory lying between Kansas and Texas. I favor insisting on the use of the term Permian and let its rank stand as others have given it until somebody is ready to tell us in detail and in a connected way what we have in Kansas, Indian Territory, and Texas. As far as I can see the indications now are that the Permian ultimately, with the Red Beds included, shall be entirely separated from the Carboniferous.[2]

In 1891 Dr. Th. Tschernyschew, the former able director of the Russian Geological Survey and the authority on the middle and upper Paleozoic of Russia, in company with Professor H. S. Williams, examined the rocks as exposed along the Kansas river from Manhattan to Fort Riley. Their conclusions were reported as follows by Mr. Robert Hay: "While agreeing that the lower beds [at Fort Riley] are Permo-Carboniferous, they state that the upper beds—where the Phacoceras is—are decidedly Permian, the Russian professor assuring me that both

[1] GOULD, JOUR. GEOL., Vol. IX, 1901, pp. 337–41; BEEDE, *Am. Geol.*, Vol. XXVIII, 1901, pp. 46, 47; and *Adv. Bull. First Bien. Rept. Okla. Geol. Surv.*, 1902, pp. 1–11.

[2] Letter of December 16, 1898.

faunal and lithologic characters can be duplicated in the Permian of his own country."[1] The specimens of *Phacoceras* and other Cephalopods from Fort Riley and Junction, Kansas, were identified and described by Professor Alpheus Hyatt and came from the Fort Riley limestone. Therefore, according to the above statement Dr. Tschernyschew correlated the Fort Riley limestone and superjacent Paleozoic formations with the Permian of Russia.

Correlation of the Kansas and Texas beds.— Professor Cummins reported that:

> The *Phacoceras Dumblei*, Hyatt, has been found only along a very narrow horizon in the Texas Permian. . . . . This fact will assist materially in correlating the Texas and Kansas beds, as that fossil has been reported only from cne locality in the Kansas area, where it is associated with the same fossils as in Texas. It is quite certain that the Fort Riley horizon is the same as the Wichita division of Texas, and is at the very top of the division.[2]

In ascending order the divisions of the Texas Permian as described by Professor Cummins are the Wichita, Clear Fork and Double Mountain;[3] while the Albany division[4] was left "as the top of the Coal-measures"[5] although the statement was made that "It may be that the Wichita and Albany divisions are but different facies of the same formation" for the Wichita division north of the Brazos river "occupies the same position, stratigraphically, as the Albany beds on the south."[6] Later Professor Cummins proved the correctness of the latter supposition and stated that he "found the fact well established that the Wichita and the Albany divisions were the same in time of deposition, and therefore the Albany must be abandoned both as to its name and the age to which I had previously referred it, and

[1] *Trans. Kan. Acad. Sci.*, Vo XIII, 1893, p. 38.

[2] *Trans. Texas Acad. Sci.*, Vol. II, 1897, pp. 97, 98. Also see D. W. Johnson, in *Bull. Sci. Lab. Denison Univ.*, Vol. XI, 1900, p. 223.

[3] *Geol. Surv. Texas, Second Ann. Rept.*, 1891, pp. 361, 373. *Fourth ibid.*, 1893, pp. 224–32.

[4] Prof. Hill has shown that the Albany division of Cummins is the same as the one named and described at an earlier date by Prof. Tarr as the Coleman. *Twenty-first Ann. Rept. U. S. Geol. Surv.*, Pt. VII, 1902, pp. 96, 97).

[5] *Ibid.*, p. 224. [6] *Ibid.*, p. 223.

the beds composing the division must be referred to the Wichita division of the Permian. Since the Wichita division is now made to include the area heretofore referred to as the Albany division, it becomes at once the most important and interesting part of the Permian in North America."[1] And he concluded with the statement that "it has been determined that the Albany division, with its numerous fossils, is but another facies of the Wichita division which is beyond question Permian."[2]

If Professor Cummins be correct in correlating the Fort Riley limestone with the top of the Wichita division of Texas it very decidedly supports the reference of the Upper Paleozoic formations of Kansas to the Permian. He had stated that all the typical localities of invertebrate fossils described by Dr. C. A. White were included in the Wichita division, "the greatest number of vertebrate fossils described by Professor Cope" and the fossil flora described by Dr. I. C. White;[3] while the *Phaco-ceras Dumblei* "was taken from the very top of the Albany division."[4]

The fossil named and described by Professor Heilprin as *Ammonites Parkeri* which was reported from rocks of Carboniferous age in Wise county, northern Texas,[5] was referred to *Popanoceras* by Professor James P. Smith[6] who stated, on the authority of Professor Cummins, that the *Popanoceras Parkeri* beds are in the Strawn [Richland] division and therefore of the age of the Lower Coal-measures.[7] The occurrence of this type in the Texas beds, however, led Karpinsky in 1889 to write as follows: Since the Popanoceratidæ up to the present time have not been found in other countries in deposits which are older than the Permo-Carboniferous (in which the commonest Ammonites occur),

[1] *Trans. Texas Acad. Sci.*, Vol. II, 1897, p. 97. Also see JAMES P. SMITH, *Proc. Am. Phil. Soc.*, reprint, 1896, p. 13.

[2] *Trans. Texas Acad. Sci.*, Vol. II, 1897, p. 97.

[3] *Geol. Surv. Texas, Fourth Ann. Rept.*, p. 225. Also see *Trans. Tex. Acad. Sci.*, Vol. II, 1897, pp. 94, 95.

[4] *Geol. Surv. Texas, Fourth Ann. Rept.*, p. 223.

[5] *Proc. Acad. Nat. Sci. Philadelphia*, 1884, Vol. 36, pp. 53–5.

[6] JOUR. GEOL., Vol. II, 1894, p. 194; and see "Correlation Table" on p. 204.

[7] *Proc. Am. Phil. Soc.*, Vol. XXXV, 1896, reprint, p. 16 f *.

therefore in my opinion the Texas deposits must rather be assigned to the Permo-Carboniferous.[1]

In 1891 came Dr. C. A. White's description of "thirty-two species of invertebrates . . . . . from the Texan Permian," of which four Cephalopods belonging to the family *Ammonoidea* were recognized as new. It was stated that two of these types, *Waagenoceras Cumminsi* and *Popanoceras Walcotti*, "are so generally regarded as indicating the Mesozoic age of the strata containing them that if they alone and without any statement of correlated facts had been submitted to any paleontologist he would not have been warranted in referring them to an earlier period than the Trias if he had followed the usually accepted standard of reference."[2]

In conclusion Dr. White stated that "The evidence upon which the Texan strata have been referred to the Permian is fuller than that which has been adduced with regard to any other North American strata that have been so referred. That is, the evidence both of the vertebrate and invertebrate fossils is in favor of such reference, and the difference in the character of the strata from those of the underlying Coal-measures, although not great, is conveniently distinguishable;"[3] while he was inclined to consider the Texan Permian as of younger age than the Indian and Sicilian strata containing the commingled Mesozoic and Carboniferous forms which were described by Professors Waagen and Gemmellaro.

Waagen correlated the "Red sandstones and shales of Texas, with many remains of Vertebrates, *Amphibia* and *Reptilia* and *Goniatites Baylorensis*, *Hyattoceras Cumminsi*, *Medlicottia Copei* and *Popanoceras Walcotti*" with the "Weissliegendes and marl slate" which he put at the base of the magnesian limestone, that formed the upper division of his Permian system.[4]

Marcou stated "It is certain that the Wichita division belongs

[1] *Mém. Acad. Imp. Sciences St. Pétersbourg*, VII[e] Sér., t. XXXVII, No. 2, 1889, p. 93. Also see the correlation of the Texas deposits as shown in Table C, p. 94.

[2] *Bull U.S. Geol. Surv.*, No. 77, p. 31. [3] *Ibid.*, p. 38.

[4] *Mem. Geol. Surv. India*, *Palæ*, *India*, ser. xiii, "Salt-Range Fossils," Vol. IV, Pt. II, "Geological Results," 1891. Tabular View showing the relations of the Salt-Range Upper-Palæozoic strata to the deposits of other countries, op. p. 238.

to the Dyas (Permian)"[1]; while in considering the list of fossils given by Cummins he said: "It is a fauna related with the Russian fauna of the Artinsk beds, and may be considered as the American representative of a part of the Russian Dyas (Permian)."[2]

Professor James P. Smith stated that "the Ammonite-bearing beds of northern Texas, described by Dr. C. A. White . . . . . belong above the Artinsk stage, and in the true Permian, and are probably of the same age as the middle division of the *Middle Productus* limestone of the Salt Range [India]."[3]

Dr. Keyes in discussing the parallelism between the Texas and Kansas beds said, "The Double Mountain beds are, in a broad way, manifestly approximately equivalent to Cragin's Cimarron series. This leaves a considerable part of the Clear Fork beds representing the Chase and Marion of Kansas."[4] Professor de Lapparent considered that in northern Texas the Uralian with *Productus cora* and *Athyris subtilita* is succeeded conformably by 300 meters of sandstones and shales, occasionally calcareous, in which the red color predominates, the base of which appears to belong in the Artinsk.[5] He stated that the red gypsiferous beds with *Pleurophorus* which in the western part of Texas surmount the Wichita formation belong in the Upper Permian.[6] Finally, Dr. Frech puts the Wichita and Clear Fork beds in the Palaeo-Dyas and the Double Mountain beds in the Neo-Dyas[7] and states that the Ammonoids described by Dr. White — *Medlicottia Copei*, *Popanoceras Walcotti* and *P.* (*Hyattites*) *Cumminsi* have their nearest relatives in the marine Dyas of Sicily.[8]

Provisional correlation of the Kansas formations.—The above statements indicate clearly enough the differences in opinion among geologists more or less acquainted with the Upper Paleozoic formations of the Great Plains, regarding their correlation. It is to be noted, however, that there is a more general agreement regarding the Permian age of the Texas deposits, and if Professor

[1] *Amer. Geol.*, Vol. X, 1892, p. 370. [2] *Ibid.*, p. 371.

[3] JOUR. GEOL., Vol. II, 1894, p. 194; and see "Correlation Table" on p. 204.

[4] JOUR. GEOL., Vol. VII, 1899, p. 325.

[5] *Traité de Géologie*, 4th ed., 1900, p. 981. [6] *Ibid.*, p. 994.

[7] *Lethaea palæozoica*, Bd. II, 3 Lief., 1901, p. 514. [8] *Ibid.*, p. 515.

Cummins has correctly correlated the Fort Riley limestone with the Texas deposits it furnishes a strong argument in favor of referring the Upper Paleozoic formations of Kansas to the Permian.

Furthermore, the number of American geologists who believe that these Upper Paleozoic formations should be correlated with the Permian and given the rank of a period or system is probably still smaller than the number of those who would retain the name Permian but classify it as the upper series of the Carboniferous. The writer had hoped to carefully study the fossils of these formations and to present their complete evidence regarding these questions, but other duties have prevented the execution of this plan. It has appeared to me, however, that the weight of evidence favored correlating the upper formations with the Permian.

Whether the Permian should be assigned the rank of a system coördinate with the Carboniferous or regarded as the upper subdivision of it is not quite clear, and the line of division between the Permian and the Carboniferous is in doubt, as indicated on the chart p. 730. The opinions of some of the leading European students of the Upper Paleozoic, who regard the Permian as a distinct system and correlate certain American formations with it, has seemed to the writer sufficient authority for provisionally regarding it as a system, which was done in the table of classification opp. p. 704. It is probable, however, that the U. S. Geological Survey will retain the name Permian, but will classify it as the last series of the Carboniferous system.

Conclusions of Dr. Keyes.— No one has, perhaps, insisted as strenuously as Dr. C. R. Keyes that the name Permian should be dropped from American geology. In 1897 he attended the sessions of the International Congress of Geologists at St. Petersburg and participated in the excursions to the Carboniferous and typical Permian of Russia. Later he prepared a paper on the "American homotaxial equivalents of the original Permian," and quotations from this cannot be regarded as from one favoring the retention of the name "Permian." Regarding the lithologic features Dr. Keyes said :

The original Permian strata are indistinguishable, lithologically, from the so-called Permian of Kansas. In both there are the same gray and variegated sandy shales and marls, passing locally into sandstones, that are often copper-bearing. Occasionally there are present thin bands and beds of buff earthy limestone. Gypsum is abundantly developed in the beds and interspersed everywhere through the rocks. Saline shales are of not infrequent occurrence. On both continents all these pass upward into "Red Beds" that are almost destitute of fossils.

And in another paragraph is a striking statement that "In the Russian district one finds it difficult to imagine that he is not wandering through some part of Kansas. Only the presence of the Russian peasant or sudden contact with a village of the steppes dispels the illusion."

Secondly, under the heading, "Range of faunas," Dr. Keyes reported as follows regarding the fossils:

The succession of faunas appears to be essentially the same in the Russian Carboniferous and Permian as in the Mississippi valley. The composition of each of the faunas is also strikingly comparable. The most noteworthy feature of the organic remains, viewed as a whole, is the gradual replacement of a purely marine type by a shore and brackish water phase, as the change from open sea to closed water conditions took place, and finally to those in which life could not exist. The most prominent characteristic of the biotic change from a Carboniferous phase to a Permian one seems to be the replacement of a predominantly brachiopod fauna by one in which lamellibranchs formed the preponderant element.[1]

While in another article Dr. Keyes said: "In lithological and faunal characters the rocks are so nearly alike that it is difficult to fancy that in the Urals one is on the opposite side of the earth from our Iowa and Kansas beds."[2]

Under the general heading, "Comparison of the Russia and Mississippi Valley Carboniferous," and subheading, "Stratigraphic parallelism," Dr. Keyes stated that "In Russia and in the Mississippi valley the general geological sections of the Upper Paleozoic are remarkably alike. The basins occupied by these rocks are very nearly of the same size. As already stated in the first-mentioned area, the Permian very greatly predomi-

[1] JOUR. GEOL., Vol. VII, 1899, p. 334.

[2] "Permian Rocks of Eastern Russia," in *Proc. Iowa Acad. Sciences*, Vol. VI, 1899, p. 231.

nates as the surface rock; in the last-named, the Coal-measures."[1] While the above paragraph is followed by the following "Comparison of general sections" in Russia and the Mississippi valley, which may evidently be regarded as Dr. Keyes's idea of the correlation of the upper Paleozoic rocks of the central United States and Russia.

Russia.	Character of Terranes.	Mississippi Valley.
Tartaran, Permo-Trias, or Upper Permian, P_3	Shales and marls, red and variegated, shaly sandstones; fossils rare; "Red Beds"	Cimarron Series
Middle Permian, P_2	Limestones, some dolomitic, separated by calcareous marl	(Marion li.) } Series
Lower Permian, P_1-b	Shales (only 200 feet thick in Kama Valley)	——— ?
Upper Permo-Carboniferous (base of original Permian) CP_c	Limestone, heavy dolomitic	(Chase li.)
Artinsk, CP	Shales, sandstones, some thin limestones	(Neosho) (Cottonwood) (Wabaunsee) } Series
Upper Carboniferous, C_3	Limestones and shales, highly fossiliferous	Missourian Series[2]

Finally, in his "Recapitulation" it is stated "That while we have in America a great succession of deposits identical in all essential respects to the original Permian of Russia, the two great basins merely had similar histories that are not necessarily connected and doubtless were wholly independent of each other and unrelated."[3]

Dr. Keyes's description and comparison of rocks and faunas apparently support the correlation of the Upper Paleozoic of the Great Plains with the Permian of Russia, providing one follows

[1] Jour. Geol., Vol. VII, 1899, pp. 331, 332.

[2] *Ibid.*, p. 332; *Proc. Iowa Acad. Sciences*, Vol. VI, p. 230.

[3] Jour. Geol., Vol. VII, p. 341; *Proc. Iowa Acad. Sciences*, Vol. VI, p. 231.

the rules of correlation generally observed by geologists.[1] The evidence is apparently about as conclusive as for other systems in this country which are correlated with the Carboniferous, Devonian, or Silurian of Europe. Apparently the main point of Dr. Keyes' contention is "That [the] Permian, as originally proposed, applies to a provincial series, and, according to our usual standard, has, at best, a taxonomic rank below that of system."[2] Yet he states it is probable that its main subdivisions will be elevated "to the rank of series," which, instead of causing the name Permian to be dropped, as he suggests, will more probably leave it with the rank of a system as originally defined by Murchison. A geologist familiar with the Kansas formations wrote as follows concerning the provincial series question: "Grant, as Keyes maintains, that Permian is the name of a provincial series, then where a similar series is found with similar fossils the same name ought to be given. All our names were names of provincial series at first. What was Devonian but the name of a series of rocks in Devonshire, England? When found in New York, by this argument, they should be called New Yorkian or some other American name."

The conclusions of Dr. Frech.—On the other hand, the conclusions of Dr. Fritz Frech, the eminent professor of geology and paleontology in the University of Breslau, may be considered. He has carefully studied, both in the field and laboratory, the Permian of Germany and Russia and examined in the field the Permian of the United States, at least as shown in the Grand Canyon and near Salt Lake City, Utah.[3] Dr. Frech gives these rocks the rank of a system, which is also the usage of Dr. Kayser, of the University of Marburg,[4] but instead of Permian he

[1] For instance, if his account be compared with the list of physical and biotic methods of correlation given by Professor Gilbert at the Washington meeting of the International Congress of Geologists, it will be seen that several of the methods are fulfilled (Congrès Géologique International, *Compte Rendu*, 5[me] session, Washington, pp. 68, 69).

[2] *Loc. cit.*, p. 341; and p. 231.

[3] See *Congrès Géologique International, Compte Rendu*, 5[me] Ses., Washington, 1891, 1893, p. 481; and *Lethaea palæozoica*, Bd. II, 3 Lief., 1901, p. 515.

[4] See *Text-Book of Comparative Geology*, by E. KAYSER, translated and edited by Philip Lake, 1893, p. 164.

uses the later name of Dyas proposed by Marcou on account of the sharply marked separation of the system into two divisions in Germany.

Dr. Frech's classification of the Upper Paleozoic of Kansas is as follows:

Upper Dyas	Red shales and clays. Marion.
Lower Dyas	Chase.
Transition to Carboniferous (distinct line fails.)	Neosho. Cottonwood beds.
Upper Carboniferous	Wabaunsee.[1]

Later Dr. Frech reviewed Professor Cragin's classification of the Permian, and termed the Cimarron series the "Neo-Dyas," and the Big Blue series the "Paleo-Dyas."[2] He stated that the Dyas equaled the Permo-Carboniferous plus the Permian of many authors, and that by general agreement at the St. Petersburg International Congress of Geologists the names Paleodyas (=Permo-Carboniferous) and Neodyas (=Zechstein) are employed.[3]

Under the discussion of the boundary line between the Dyas and Carboniferous Dr. Frech said: The dividing line between the Carboniferous and Dyas formations cannot be drawn with full certainty in every region, since especially in the Dyas the development of the local flora is nearly always the rule, and decisive differences do not exist in the Brachiopod fauna.

Yet an agreement seems to be gradually forming everywhere. . . . . Where the characteristic Dyas bivalves (*Pleurophorus*, *Schizodus*, *Bakewellia*, *Pseudomonotis*) appear in masses (Kansas), there cannot be any doubt about the dividing line.[4] Under the description of the Dyas of the northern hemisphere and the Arta stage of Russia, as Dr. Frech prefers to call the Artinsk, he said: That the animal remains of the Permo-

[1] *Lethaea palæozoica*, Bd. II, 2 Lief., 1899, p. 378, as translated above.

[2] *Ibid.*, 3 Lief., 1901, p. 514. [3] *Ibid.*, p. 453 f.

[4] *Ibid.*, pp. 490, 491. I am greatly indebted to Charles W. Mesloh, associate professor of Germanic languages and literatures in the Ohio State University, who very kindly translated for me several pages of Dr. Frech's description of the Dyas.

Carboniferous are in general more nearly related to the Carboniferous than the Zechstein, finds its explanation in the poverty of the species of the inland seas. The Arta stage occupies a large space on the western slope of the Ural mountains from the Arctic ocean to the Kirghiz Steppe and the Donetz River, and was correctly classified with the Dyas by older investigators (Pander). The plant remains described by Schmalhausen speak quite decidedly for a comparison with the western Rothliegende[1] Murchison considered the Arta sandstone the Millstone grit, while the modern Russian authors mostly call it an intermediary stage from the Carboniferous to the Dyas, Permo-Carboniferous. If the latter assumption were correct, then the Cusel and Lebach strata would also have to be regarded as transitional from the Carboniferous to the Zechstein, *i. e.*, the most important and best known part of the formation would become a transition and only the equivalent of the German Zechstein would be designated as Permian.[2]

Usage of Russian geologists.—Among the recent Russian geologists who have described transitional deposits between the Carboniferous and Permian systems, may be mentioned the following: Krotow, who in 1888 described the Permo-Carboniferous and Permian on the western slope of the Urals in the region of Tscherdyn and Solikamsk.[3] Th. Tschernyschew, in 1889, described the Permo-Carboniferous of the western slope of the central Urals, which he lettered C P, and gave as composed of the Artinsk (C Pg), and superjacent Dolomitic limestone (C Pc), the latter forming the base of Murchison's Permian system.[4] Krasnopolsky, the same year, described the Permo-Carboniferous and Permian deposits of another portion of the western Urals,[5] which was followed two years later by a further description.[6] Stuckenberg, in 1890, described the Permo-Carboniferous of another region, which he gave as composed in ascending order

[1] *Ibid.*, pp. 493, 494. [2] *Ibid.*, p. 493, f. 2.

[3] *Mém. Comité Géologique*, Vol. VI, pp. 553–9.

[4] *Ibid.*, Vol. III, No. 4, Blatt 139, pp. 356–66.

[5] *Ibid.*, Vol. XI, No. 1, Blatt 126, pp. 506–18.

[6] *Ibid.*, No. 2, 1891, pp. 28–30.

of the Artinsk and Kungur stages.[1] Sibirzev, in 1896 carefully described the Permian deposits near Nishny-Novgorod on the Volga, together with those of the Permo-Carboniferous farther to the west;[2] while Stuckenberg two years later described in a similar manner the Permo-Carboniferous and Permian formations of the Kama basin.[3]

Since then Dr. Keyes has very clearly summarized the Russian classification of the Upper Paleozoic terranes of eastern Russia in the following table:[4]

Terrane.	Symbol.	Character.
Tartaran	PT or P_3	Shales and marls, "Red Beds," very few fossils.
Zechstein (in part.)	P_2	Marls, limestones, and sandstones.
....	Pb	Sandstones, shales, and marls with nodular limestones.
....	C Pc	Dolomitic limestones (base of Murchison's Permian).
Artinsk	C Pg	Shales, shaly sandstones. This and next terrane above are called Permo-Carboniferous.
....	C_3	Limestones.

Dr. Keyes states that following "the so-called true Carboniferous of the Urals . . . . are the transition faunas to the Permian, according to the Russians, and by them called Permo-Carboniferous. The two members which comprise it contain, as pointed out by Tschernyschew, very nearly the same organic forms, consisting largely of lamellibranchs, gasteropods, and brachiopods. The lower terrane, termed the Artinsk is notable for the ammonites that are found in it, which the author just mentioned compares with those lately found in the Texas Permian. . . . .

"The bottom terranes of the Permian, as now recognized by the members of the Russian geological survey, present a great paucity of fossils. The forms are chiefly lamellibranchs, yet in some layers are fragmentary plants.

"The median part of the Permian carries what has been regarded as the typical German Zechstein fauna.

[1] *Ibid.*, Vol. IV, No. 2, Blatt 138, pp. 111–14.

[2] *Ibid.*, Vol. XV, No. 2, Blatt 72, pp. 242–65.

[3] *Ibid.*, Vol. XVI, No. 1, 1898, pp. 309–21.

[4] Jour. Geol., Vol. VII, 1899, p. 330.

"About the upper terrane there is much dispute as to age. The Russian geologists are about equally divided. Amalitzky considers it Permian. By others it is regarded as Triassic. Fossils occur rarely. Those found are chiefly lamellibranchs."[1]

OPINIONS OF OTHER EUROPEAN GEOLOGISTS.

There are other noted European geologists, however, whose conclusions are in general accord with those of Dr. Frech.

Waagen, in his magnificent work on the geological classification of the Upper Paleozoic rocks of the Salt-Range in northern India, ranked the Permian as a system which he divided into the three following groups, arranged in ascending order: Permo-Carboniferous, Rothliegendes and Magnesian limestone. He published a table showing the correlation of the Upper Paleozoic strata of the Salt-Range with similar deposits of other countries on which the "red sandstones and shales of Texas," containing vertebrates and invertebrates which have been described by Cope and White, were correlated with the lower part of the Magnesian limestone, or upper group of his Permian system. The "limestones and shales, with *Pseudomonotis hawni* (——*speluncaria*) of Kansas, red gypsum beds of Texas"[2] were regarded as equivaalent to the remaining portion of the Magnesian limestone group and consequently represent the upper part of the Permian system.

De Lapparent, in the last edition of his comprehensive treatise of geology, gives the Permian the rank of a system[3] to the lowest stage of which, the Artinskien or Autunien, he refers the Neosho, Chase and Marion terranes of central Kansas. It is stated that it would be difficult to class elsewhere than in the Artinskien, the Neosho and the Chase, although there may be a doubt regarding the correlation of the Marion.[4] On his table of "Synchronism of Permian assises," beds with *Pleurophorus* and with *Pseudomonotis* of Kansas are given as in the Thuringien or Upper Permian stage,[5] while on the following page it is stated

[1] *Ibid.*, pp. 330, 331.

[2] *Mem. Geol. Surv. India, Palæ.*, India. Series 13, Salt-Range Fossils, Vol. IV, Pt. II, Geol. Results, Calcutta, 1891, op. p. 238.

[3] *Traité de Géologie*, 4th ed., Pt. II, 1900, pp. 759–963.

[4] *Ibid.*, pp. 980–1. [5] *Ibid.*, p. 993.

that in the Upper Permian is, perhaps, also the horizon of the upper limestones and shales of Kansas with *Pseudomonotis Hawni*, which surmount 75 meters of variously colored shales and marls, with gypsum (assise de *Marion* de M. Prosser).[1]

It is to be noted, however, that de Lapparent is in error in correlating the sandstones and shales of Nebraska with the lower part of the Penjabien or Saxonien, which he classifies as the Middle Permian.[2] Such a classification puts the Nebraska City beds at least above the Neosho and Chase, as is clearly indicated on his table of synchronism, while as a matter of fact it has been shown by Dr. Beede and the writer that they are probably equivalent "to the Topeka limestones and Osage shales of the Kansas river section, which form the upper part of Professor Haworth's Shawnee formation of the Upper Coal-measures."[3] The rocks included between the top of the Shawnee formation, which is marked by the base of the Burlingame limestone, and the top of the Chase stage have an approximate thickness of 950 feet in eastern central Kansas, which gives an idea of the stratigraphic error when the Nebraska City beds are assigned to a position above the Chase stage.

In discussing the rank of the Permian de Lapparent wrote: The marine types of the Permian, scarcely known until recent years, show in Asia as in the United States greater and greater development. Finally, the well confirmed discovery of Ammonites with arborescent septæ gives to the pelagic fauna of the period a special character, at the same time that by the first appearance of true reptiles the terrestrial fauna shows a higher order than that of the preceding period. Therefore, we, agreeing with the excellent arguments of Neumayr in his *Erdgeschichte*, raise to the rank of system this last division of Primary time.[4]

Finally, from among the other famous European geologists who rank the Permian as a system and have written in support

[1] *Ibid.*, p. 994. [2] *Ibid.*, pp. 986–93.

[3] JOUR. GEOL. Vol. VII, Aug., 1899, p. 346. Also, see PROSSER, *ibid.*, Vol. V, March, 1897, p. 148; and BEEDE, *Kan. Univ. Quart.*, Vol. VII, Oct., 1898, Series A, p. 231; and *Trans. Kan. Acad. Science*, Vol. XVI, 1899, p. 70.

[4] *Ibid.*, p. 964.

of this proposition may be mentioned the following: Credner,[1] Prestwich,[2] Neumayr,[3] Sir Archibald Geikie,[4] Ed. Suess,[5] and Karl v. Zittel.[6]

CHARLES S. PROSSER.

COLUMBUS, OHIO,
June, 1902.

The question as to whether the Alma limestone should be substituted for the Cottonwood limestone on account of the earlier name of Cottonwood Creek beds in Texas was submitted to the U. S. Geological Survey Committee on Formation Names and under date of October 29, 1902, Dr. C. Willard Hayes has sent me the following report of the committee:

This committee approved the name *Cottonwood limestone* at its meeting March 29, 1902, and at that time considered the priority of *Cottonwood Creek beds, Texas*. It decided at the time that, although the latter name had priority of usage, it probably was not a clearly-defined formation but merely a bed of unmapable dimensions. Also that inasmuch as *Cottonwood Creek beds* has not occurred in literature since its first usage in 1893, and whereas *Cottonwood* (*Cottonwood Falls*) *formation* has been used thirteen times since its first usage in 1894, the latter name has acquired a place in literature on the grounds of prescription. The committee therefore decided to adhere to its former decision in favor of *Cottonwood limestone*."

In compliance with the above decision the writer withdraws the name Alma limestone and retains Cottonwood limestone as the name of the Kansas formation.

C. S. P.

October 31, 1902.

[1] *Elemente der Geologie*, 6th ed., 1887, pp. 382–507.

[2] *Geology, Chemical, Physical and Stratigraphical*, Vol. II, 1888, pp. 8–131.

[3] *Erdgeschichte*, Bd. II, 1890, pp. 37–199.

[4] *Text-Book of Geology*, 3d. ed., 1893, "The Geological Record," op. p. 679 and p. 841.

[5] *La face de la terre*, translated by EMM. DE MARGERIE. T. II, 1900, p. 407.

[6] *History of Geology and Palæontology*, translated by MARIA M. OGILVIE-GORDON, 1901, p. 453.

ON SOME GLAUCOPHANE AND ASSOCIATED SCHISTS IN THE COAST RANGES OF CALIFORNIA.[1]

The blue amphibole or glaucophane schists of the California Coast Ranges, with which are genetically associated actinolite and garnet schists, have been objects of considerable geologic interest since they were first observed in 1877. They have been cited by Mr. H. W. Turner,[2] Dr. H. W. Fairbanks,[3] and by others from many parts of the Coast Range mountains, throughout which they are abundant.

The schists occur to a large extent as rather massive isolated outcrops, and, in general, do not show their schistose structure except upon a near examination. They vary in texture from layer to layer; a hard, compact quartzose sheet being succeeded by a wrinkled, elastic, micaceous layer, which may be followed by a dense massive variety containing but little mica. These schists are for the most part entirely crystalline, and are principally characterized by the abundance of blue amphibole or glaucophane, which they contain. Whether this blue amphibole is mainly glaucophane, crossite or riebeckite the writers have not determined. There appear to be at least two varieties of the blue amphibole present in the series, one with a wide angle between the optic axes and strong double refraction, and another with a very narrow angle and weak double refraction. For the sake of convenience, however, and in accordance with the general practice, the blue amphiboles will be referred to in this paper as glaucophane.

[1] The writers are indebted to Dr. J. P. Smith, of Stanford University, for assistance and advice.

[2] "Notes on Some Igneous, Metamorphic and Sedimentary Rocks of the Coast Ranges of California," H. W. Turner, Jour. Geol., Vol. VI, p. 488 *et seq.*; "The Geology of Mount Diablo, California," H. W. Turner, *Bull. Geol. Soc. Am.*, Vol. II, p. 385.

[3] "The pre-Cretaceous Age of the Metamorphic Rocks of the California Coast Ranges," H. W. Fairbanks, *Am. Geol.*, Vol. IX, p. 160; "Notes on a Farther Study of the pre-Cretaceous Rocks of the California Coast Ranges," H. W. Fairbanks, *Am. Geol.*, Vol. XI, pp. 70–73.

Of less importance though widely distributed and intimately associated with the glaucophane is the light green actinolite schist which occurs with the glaucophane schist in irregular layers and masses. Both of these schists have garnets abundantly developed in them.

Dikes of serpentinized peridotite and also of diabase are commonly found in apparent association with the schists. It was on such an association that Dr. F. L. Ransome[1] based his hypothesis that the Angel Island glaucophane schist is the result of the contact action of fourchite and peridotite intrusions in the Golden Gate or Franciscan sandstones. Ransome's conclusions are questioned, however, by Turner,[2] who says: "It is yet to be demonstrated that these schists are the result of contact metamorphism."

In a short note in his paper on metamorphism, Professor C. R. Van Hise[3] refers to the glaucophane schists of the northern end of Calaveras Valley, in Alameda county, as resulting from dynamic agencies, and says they are formed from igneous rocks by crushing.

The writers have examined several localities where the schists occur, and where their relationship with accompanying rocks is clear. The principal ones are four in number: one about two miles southwest of Healdsburg, Sonoma county, one at Camp Meeker, Sonoma county, one mentioned by Van Hise in the northern end of Calaveras Valley, Alameda county, and one on Tiburon Peninsula, Marin county, in which the lawsonite described by Ransome[4] occurs. Besides these, many smaller exposures have been studied between Healdsburg and San Luis Obispo county, and especially in the region around the bay of San Francisco.

[1] "The Geology of Angel Island," F. Leslie Ransome, *Bull. Dept. of Geol. Univ. of Calif.*, Vol. I, No. 7, p. 211.

[2] *Loc. cit.*, p. 491.

[3] "Metamorphism of Rocks and Rock Flowage," C. R. Van Hise, *Bull. Geol. Soc. Am.*, Vol. IX, p. 313.

[4] "On Lawsonite, a New Rock-Forming Mineral from the Tiburon Peninsula, Marin county, California," F. Leslie Ransome, *Bull. Dept. Geol., Univ. of Calif.*, Vol. I, No. 10, p. 311.

Healdsburg.—At Healdsburg the schist area is nearly a mile wide and more than four miles long. The thickness of the schist is several hundred feet, though no exact measurements have been made. From about half a mile south of the Junction Schoolhouse, which is two miles southwest of Healdsburg, the schists form a range of hills which extend in a general northwesterly direction for several miles. In the southern end of this area the schists are in contact with serpentine, and overlie a boss or laccolite of it. The contact is clear and unmistakable, as the rocks stand up above the soil, and hand specimens may be secured which show the parting between the schist and serpentine in a single fragment. In the serpentine boss is an irregular mass of gabbro—possibly a result of magmatic differentiation. In addition there are at least three serpentinized dikes in the schist area northwest of the Junction Schoolhouse, and also a small outcrop of diabase.

With the exception of one place where it grades into shale, the schist is entirely crystalline, and is composed mainly of glaucophane, actinolite, garnet, epidote, and various light-colored micas. Some layers are very quartzose and are composed mainly of quartz, glaucophane, garnet, epidote and a little white mica. The schists vary much in texture and mineral composition, but are easily recognized, as there are no other rocks like them in this locality.

South of the Junction Schoolhouse a fragment of actinolite schist was found in the serpentine, and its plane of schistosity makes a large angle with the planes of neighboring masses of schist. It is clearly an inclusion and points definitely to the serpentine being intrusive in and younger than the schist. Ransome, in his paper on the geology of Angel Island, mentions similar inclusions in the serpentine there.[1]

About a quarter of a mile southwest of the Junction Schoolhouse the schists appear to be overlain unconformably by Golden Gate or Franciscan[2] sandstones. This relation is not entirely

[1] *Loc. cit.*, p. 225.

[2] As the Franciscan or Golden Gate rocks are unfossiliferous, their identification away from the type localities is based on lithologic features and field relations, and is consequently uncertain.

certain, however, as the rocks may have been faulted into their present position. About two miles north of the Junction Schoolhouse, on the eastern flanks of the hills, are jaspers intruded by a serpentinized dike which has apparently had but little metamorphic effect.

In a hillside cut on the Healdsburg road about half a mile east of the Schoolhouse, there is an excellent gradation from slightly altered shale to entirely crystalline glaucophane and actinolite schist. Specimens can be collected showing every degree of alteration. Thin sections of the least altered shale show incipient development of glaucophane in crystalline tufts and radiate aggregates.

Camp Meeker.— At Camp Meeker, Sonoma county, about twenty-five miles southwest of Healdsburg, glaucophane and actinolite schists are developed over an area which appears to be at least a mile wide and several miles long, though the limits were not determined.

Intrusive in the schist are small dikes of a pyroxene rock which are themselves somewhat schistose, and have glaucophane, actinolite, chlorite and mica developed in them. On each side of these dikes the schist is of the normal glaucophane type and contains glaucophane, actinolite, garnets and white mica. Northeast of the schist area is a mass of serpentine, but at no point examined was the relation between the two rocks clearly shown.

About half a mile north of Camp Meeker there is a gradation from schist to shale in a distance of about three hundred feet. *The shale is hard and wrinkled*, and contains some secondary mica, but no glaucophane or actinolite.

Tiburon.—The glaucophane schist area on the Tiburon peninsula is about two hundred yards wide, and extends more or less continuously from Tiburon to north of Reed's station. Northeast of the schist is serpentine which caps the hills; and southwest are sandstones and shales. Near Reed's station, however, there is a small area of the sandstone and shales, which, on the surface, lies between the schist and the serpentine, and is in contact with the serpentine. At the immediate contact the shale is somewhat hardened but is unaltered at a distance of three feet.

Calaveras Valley. — In the northern end of Calaveras Valley, northwest of Mount Hamilton, in Alameda county, there is an area of glaucophane and related schists, which can best be studied in the canyon of the Arroyo Hondo. There are two series of glaucophane-bearing rocks in this locality; one a massive crystalline rock, one facies of which is an eclogite containing, principally, garnet, omphacite, glaucophane and actinolite. The other facies is a medium grained, light colored, banded rock composed principally of quartz, glaucophane, garnet, and white mica. The garnets are in the form of very small crystals which are included in the quartz and glaucophane.

The other series of glaucophane-bearing rocks overlies this massive one unconformably, and consists of thin bedded sandy shales having a vertical dip and a northwesterly strike. They are much contorted, however, and are hard and schistose in places. These beds are unfossiliferous, but are overlain unconformably by Lower Miocene sediments. They resemble to a large extent the sandy shales of the Golden Gate or Franciscan series, and it seems probable that they belong with those rocks. Glaucophane is developed in them irregularly, one bed being blue with it, while the adjoining one on either side may contain but little glaucophane. White mica is developed in these beds in many places, and narrow quartz veins are common.

In the southern end of the canyon are masses of serpentine, but the contacts between them and the adjoining rocks are not exposed.

In contact with the massive banded rocks is a hard, heavy, compact, greenish rock, with bands and stripes of glaucophane plentifully distributed through it. It may be an altered serpentine, but thin sections of it show no definite minerals. It is apparently a dike intrusive in the banded rock, but it has probably been altered since, and may have been subjected to the same agencies that produced the banded rock.

Conclusions. — No one explanation seems to satisfactorily account for the many different aspects and occurrences of the glaucophane and related schists. That there has been some development of glaucophane at the contact of basic igneous

masses seems certain. It seems improbable, however, that the main portion of the normal glaucophane and actinolite schists is a result of contact action. That the schists have not resulted from contact action by peridotite masses seems probable, for at some points the same masses have certainly produced but slight alteration in adjoining sandstones and shales, and the thickness and character of the schists is such that they could only have been produced by metamorphosing agents acting on a large scale. It seems difficult to believe, also, that the schists could be formed by serpentine dikes which are smaller than the schist masses themselves. Besides, the inclusions of schist in the Healdsburg and Angel Island serpentines render it almost certain that the schists are the older of the two rocks. In addition, the evidence points to the massive glaucophane rocks and normal schists being older than the Golden Gate or Franciscan series of rocks, for the schists are unconformably beneath what appears to be the Golden Gate or Franciscan rocks in the Calaveras Valley, and they probably have similar relations at Healdsburg. Finally, serpentinized dikes are frequently found intrusive in Golden Gate or Franciscan rocks, while at Mount Diablo,[1] near Gilroy,[2] and in San Luis Obispo county,[3] there are serpentine dikes intrusive in the Knoxville beds. This would of course make the dikes younger than the schists, if the schists are older than the Golden Gate or Franciscan series.

In some cases the schists have been formed directly out of sedimentary rocks, and probably in some cases out of tuffs or other igneous material. The writers have observed cases in which basic igneous dikes have had glaucophane and other secondary minerals developed in them, and have become more or less schistose.

It can hardly be doubted that glaucophane schists have been developed in rocks of different ages, and older than the Knoxville. It seems probable, also, that there is a series of

[1] *Loc. cit.*, p. 390.

[2] Communicated by Dr. J. P. Smith, Stanford University.

[3] "The Stratigraphy of the California Coast Ranges," H. W. FAIRBANKS, JOUR. GEOL., Vol III, p. 428.

glaucophane schists older than the Golden Gate or Franciscan, and the possibility suggests itself that these may be but isolated outcrops of extensive masses which underlie the Coast Ranges.

The only hypothesis that seems to satisfactorily explain the occurrences of these rocks is that they are the result of dynamic agencies, and may or may not be the products of widespread regional metamorphism.

EDWARD HOIT NUTTER,
WILLIAM BURTON BARBER.

STANFORD UNIVERSITY, CALIFORNIA,
May, 1902.

THE GEOLOGIC RELATIONS OF THE HUMAN RELICS OF LANSING, KANSAS.

UNDER the title "A Fossil Man from Kansas," Professor Williston announced in *Science* of August 1, the discovery of human remains in alluvium near the mouth of a ravine opening on the flood plain of the Missouri river near Lansing, Kansas. He gave a careful description of the circumstances of the discovery, of the nature and condition of the skeleton, and of the enveloping deposit. He confidently excluded all forms of intrusion and of burial by creeping or sliding, attested fully the true fossil nature of the remains, and referred them to that stage of the postglacial period when the Missouri river was running forty or fifty feet higher than now.

Previous to this there had been references to the discovery in the press, which had attracted the attention of Mr. M. C. Long, curator of the museum of Kansas City, who visited the locality, secured as many of the bones as practicable, brought the matter to the attention of neighboring scientists, and through them to the scientific world.

In *Science* of August 29, under the title, "Man in Kansas During the Iowan Stage of the Glacial Period," Mr. Warren Upham gave a brief statement of his observations and conclusions based on a visit to the locality on August 9, in company with Professors Winchell, Williston, Haworth, Mr. Long and others. Mr. Upham regarded the overlying deposit as loess of the Iowan age, and concluded that the skeleton had been "entombed at the beginning of the loess deposition, which would refer it to the Iowan stage of the glacial period, long after the ice sheet had receded from Missouri and Kansas, but while it still enveloped northern Iowa and nearly all of Wisconsin and Minnesota."

In the *American Geologist* for September, he presented the subject with greater fullness under the title, "Man in the Ice Age at Lansing, Kansas, and Little Falls, Minnesota." As before, the inhumation was referred to the Iowan stage of glaciation,

comparison was made with other human relics regarded as dating from the glacial period, and estimates in years of the duration of the several glacial stages were added.

In the same number of the *American Geologist*, Professor Winchell commented at length editorially upon the Lansing skeleton. He referred with implied approval to the article of Mr. Upham,

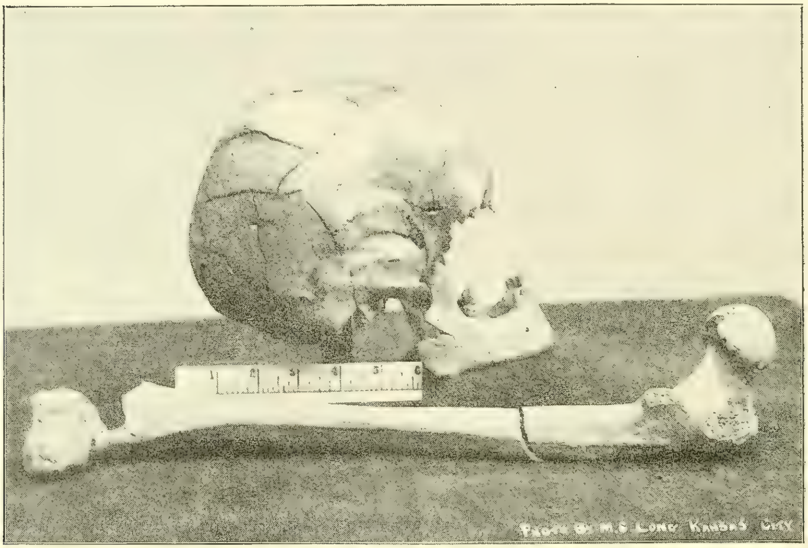


FIG. 1.— Side view of skull and femur found in the tunnel. From a photograph furnished by Mr. M. C. Long.

supplied additional information relative to the history of the discovery, to the deposit embracing the relics, and to the nature and condition of these. He regarded the main material penetrated by the tunnel as common loess, and located the skeleton in the unstratified limestone débris that lies below it. "It is hence preloessian, but probably not much older that the loess." He discussed at some length the age and relations of the loess, and concluded: "It will require, therefore, considerable further and careful examination of the loess sheets of Iowa, and of their relations to the till-sheets, as well as the marginal features of the till-sheets themselves, to enable any one to fix with any certainty

the age of the Lansing skeleton more exactly than is above indicated. That it dates from glacial time, at some remote point in the complex history of that age, is about all that can be affirmed from the present state of knowledge of the drift deposits."

On September 20 the locality was visited by Professors Samuel Calvin, W. H. Holmes, Erasmus Haworth, R. D. Salisbury, W. C. Hoad, Dr. G. A. Dorsey, Messrs. M. C. Long, F. R. Feitshaus, Martin, R. T. Chamberlin, and the writer. This visit was made at the request of Dr. Haworth and other geologists. A second visit was made on October 26 at the request of Professor Holmes and Mr. Gerard Fowke to inspect the excavations which the latter had made under the direction of the former. Mr. Long, Mr. S. J. Hare, and Dr. Haworth joined in this inspection. The Messrs. Concannon tendered all necessary privileges, as well as aid and hospitality. The following discussion is based on the data collected in these visits.

PRELIMINARY CONSIDERATIONS.

While the development of the science of river action in most of its phases is one of the gratifying achievements of recent decades, it is still to be confessed that a certain few of its aspects are among the laggard features of our science, and, as it happens, these are the ones most critically involved in the interpretation of the Lansing remains. It may not be amiss, therefore, at the outset to consider academically these special phases of fluvial action so far as essential to the present discussion.

1. *Scour-and-fill.*—One of these scantily appreciated subjects is the great depth and important function of scour-and-fill in certain of our large rivers. In this action both erosive and depositional work proceed *simultaneously.* It is well recognized that erosion and deposition may take place simultaneously in the stream bed and upon the flood plain, but the great depths and wide extent to which certain river bottoms are scoured out and promptly refilled is not always realized, nor the quick and constant reversals of this action. This is true especially of powerful rivers that flow upon a deep bed of loose material, as is the case with most of the large rivers whose bottoms were built up by

glacio-fluvial deposits during the ice age. The great examples are the larger members of the upper Mississippian system, and pre-eminent among these, the Missouri river whose bottom deposit is mainly sand and silt of an unusually mobile type. The vain struggle of the United States engineers to restrain the destructive shiftings of this river within bounds amenable to navigation and to permanent improvement on its banks, has brought out data which amply illustrate this profound instability, but this can only be fully appreciated by a detailed study of the reports of the chief of engineers.[1] Mr. L. E. Cooley, in his report for 1879, (p. 1066), makes the following among many other pertinent statements:

"To understand the difficult nature of the problem presented here [Eastport bend, on the Missouri river much above Lansing, but where the conditions are not essentially different], it is necessary to consider that at high-water, the banks are under water to a depth of three or four feet, and the current velocity is as great as seven or eight miles an hour. The erosion of the banks for several years past has been at the rate of about 1,100 feet per annum. When this was stopped by our revetment, a tremendous scour was set up, carrying the bed of the river thirty or forty feet below its normal position; in fact, the scour undoubtedly extended to the solid rock underlying the valley." And again (*loc. cit.*, p. 1071), "In many of the borings which have been made here, indurated clay balls with vegetable matter covered with a coating of sand, along with a motley collection of gravel stones, are found within a short distance of permanent strata. A precisely similar collection containing gumbo balls in a soft state was dredged from sixty feet depth at the works. These balls are from cutting banks, and the proof is conclusive that since the river has been running in silt banks as at present, scour has occasionally, at least, reached permanent strata at seventy to ninety feet depth."

Mr. Concannon informed me that eleven years ago the

[1] Professor Todd has called attention to some of these remarkable facts in his bulletin on the "Moraines of Southeastern Dakota and their Attendant Deposits," *Bull. U. S. Geol. Survey*, No. 158, pp. 150, 151.

engineers found a depth of water of ninety feet in the Missouri at a point about a quarter of a mile from his house, in what was then the channel of the river, but which is now abandoned and filled so that water covers the spot only at the highest stages of the river. Until about eight years ago the course of the river lay near the mouth of the valley in question, but is now diverted to the opposite side of the bottoms.

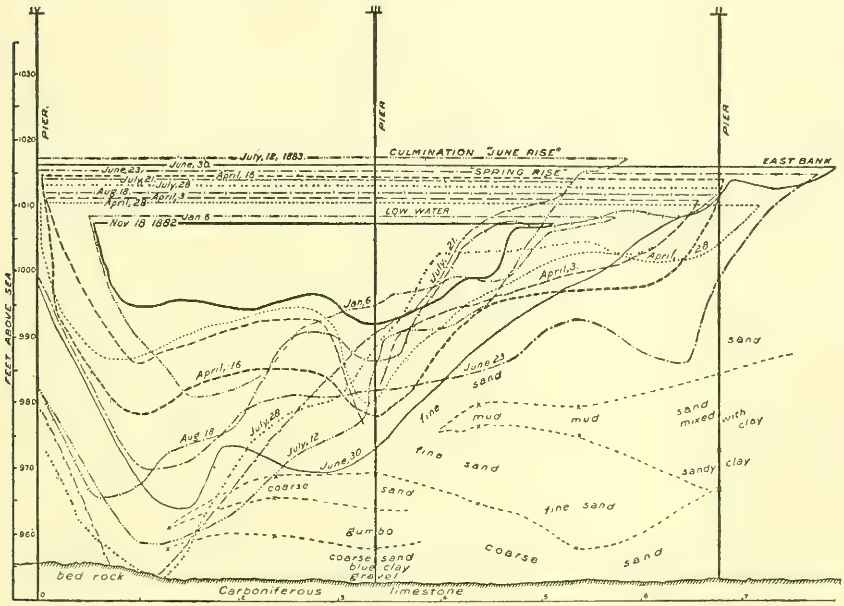


FIG. 2.—Diagram of the changes in the bottom of the Missouri river at Blair Bridge in 1883, as recorded by Engineer E. Gerber. Figure taken from Todd's *Bulletin United States Geological Survey*, No. 158, p. 151.

An accurate demonstration of the extent and rapidity of bottom changes is furnished by the accompanying diagrammatic record of the soundings at the Blair bridge, Nebraska, at the intervals indicated, in the year 1883, quoted by Todd on the authority of Mr. E. Gerber, assistant engineer F. E. & M. V. railroad.

An inspection of this will show that a skeleton might have been deposited on the surface of the Carboniferous rock bottom, much as in the case of the skeleton at Lansing, on the 28th of

July, 1883, and have been buried in alluvium as deeply as the Lansing skeleton by August 18, only twenty-one days later. Without doubt, within a few years it would be covered by sixty feet of alluvium through the migration of the channel of the river.

2. *The prevalence of this profound reworking.*— To illustrate how fully and effectually the whole of the bottoms of the Missouri river in this region are involved in its meanders and their shiftings, and how its bordering bluffs are being forced to retire by the impingement of the currents at its bends, a reduced copy of the United States Engineers' map is here introduced (Fig. 3), the section being about forty miles north of the locality in question, but representative of the conditions in all this portion of the river. It will be noted that practically the whole valley bottom is involved in the migrating loops, and that every part of its silt bed is liable to be disturbed again and again by scour and redeposit; indeed, it is probable that this has happened repeatedly to many portions, if not to most portions of the alluvial filling. It is perhaps not greatly beyond the facts to regard the whole bottom filling as being shifted, step by step down stream by successive scour and fill. This is more especially true of the borders of the bottom filling next the bluffs where the arrest and turn-about of the powerful stream gives the greatest rotatory and deep-disturbing effects.

3. *The absence of the great Dakota system of terraces.*—In the widening of the bottoms thus still in progress doubtless lies the reason why so few distinct remnants of the grand systems of glacial terraces and glacio-fluvial deposits of Dakota, described by Todd,[1] are found in this lower portion of the Missouri river. It is probable that the whole tract once occupied by these, and more besides, is now embraced by this widened, and still widening, zone of lateral encroachment. This is the less remarkable when we recall that the Missouri river was formed by the union of many preglacial streams of various connections whose lower courses were blocked up by the ice invasion so that they were

[1] *Loc. cit.*, pp. 128–140. The general nature of these is given in a later portion of the present paper.

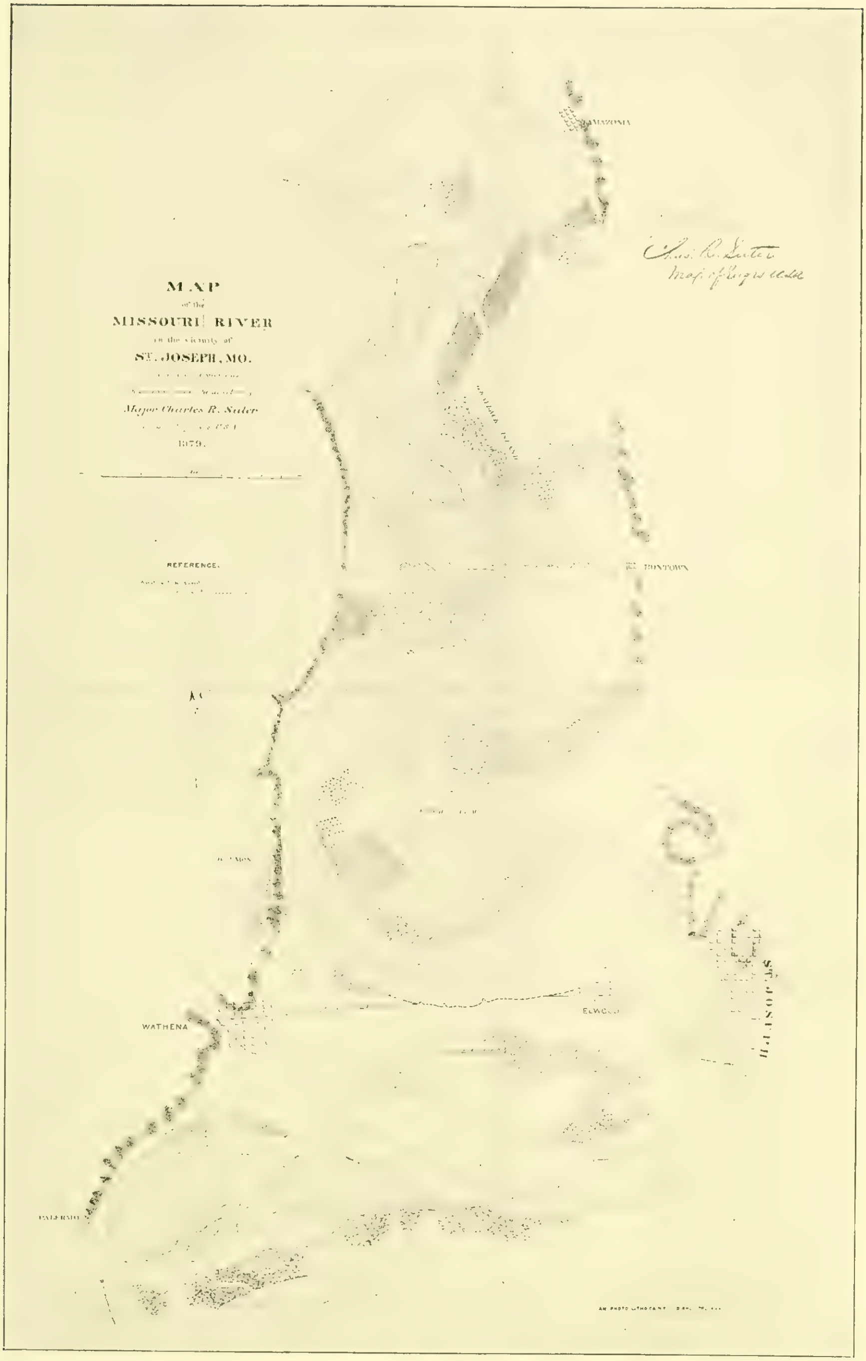


FIG. 3.—Reproduction of map of the Missouri bottoms at St. Joseph, Mo. From the *Annual Report of the Chief of Engineers for 1879.*

forced to unite and flow along the ice border. At first the newly assembled streams flowed either in the valleys of the smaller streams that entered into the combination, or in a new trench cut by the new stream across the cols between the united valleys. Thus at first it would not as a rule come into possession of a valley bottom of capacity adequate to the united floods, and in normal adjustment to them, and hence found little opportunity to make deposits. To the limited extent provided, its burden of glacial detritus was thrown down in these new and inadequate valleys, and as a natural consequence, it has been removed in the later process of working out an adequate valley and a suitable adjustment. The river is still engaged in making this adjustment.

4. *The significance of valley adjustment.*—If a great change is brought about in the drainage system of a region, such as the creation of the Missouri river by the junction of numerous antecedent rivers, and a new channel is developed to fit the new river, there at once arises the question whether the existing features of the valleys tributary to the new channel belong to the old or the new régime. In part they usually belong to both, and it becomes necessary to discriminate between these parts. This may be done by the study of their adjustments, a method especially applicable to small tributaries that have no permanent streams, as in the present case. The tributaries of the old system were adjusted to the old channel and cannot be presumed to be adjusted to the new channel, except in the rare case of exact coincidence of the old and the new channels. In relation to the new system, inherited tributaries usually present either the buried or the hanging type, or else they have become refashioned into adjustment to the new system. Such refashioning affects especially the mouths of tributaries. It often so happens therefore that refashioned configuration in conformity to the new system may dominate the mouth of a tributary, while its upper portions retain almost wholly the old configuration. These facts warn us of the danger of assigning great antiquity to fluvial deposits in the *immediate mouths* of tributary valleys if these valleys are *adjusted* to the present river or the present bottoms ; especially is this true if the tributary is scarcely more than a ravine, and

its erosion and deposition are intimately conditioned by its relation to the river. In all such cases there is a strong presumption that the erosions and depositions at the mouth of such a tributary, such especially as have brought it into adjustment to the present and to the recent stages of the river, were contemporaneous with those stages and not accidental inheritances.

5. *Meandering as a cause of alternate erosion and deposition.*—A meandering river with a deep, readily-shifted, bottom-filling of the Missouri type imposes upon its tributary valleys alternate stages of excavation and filling. These result (1) from the action of the aggressive bends of the river loops against the mouths of the tributaries, and (2), the replacement of these, after a time, by the flood-plain peninsulas that lie within the loops. More specifically, it is the alternate cutting of the stream itself, working hard against and under the mouth of the tributary valley, followed by the building up of the river's higher flood-plain across the mouth of the valley. The first causes the waters of the adjusted tributary to erode; the second to make deposits in the mouth of the tributary; for in the first stage the axis of the tributary opens out on the river itself, which may be twenty or thirty feet, or more, lower than the upper flood-plain, and hence the tributary then has its lowest and best opportunity to discharge its waters and their detrital burden. Besides this, the river itself, while in this aggressive attitude, sweeps into the mouth of the tributary in its flood stages and aids in its excavation, and the rushing by of the river's strong current drags out by friction, on the principle of draught, the waters of the tributary, and, by acceleration, aids their excavating action. It is at this stage preeminently that the tributaries cut down their valleys into adjustment with the main stream bed. On the other hand, when the active impinging bend of the river has shifted elsewhere, and in its stead a flood-plain is being built up across the mouth of the tributary the drainage of the latter is checked, and if the tributary be small and its waters incompetent in comparison with the flood-plain aggradation of the river, the valley mouth will be filled to a height corresponding to that of the highest flood-plain. Now, the difference between low water and high water for the

Missouri river is given by Abbott as twenty feet at St. Joseph, above Lansing, and as thirty-five feet at its mouth; its extreme range is somewhat greater than this.

Further, if the mouth of the tributary be blocked by the upper flood-plain beyond the time of the latter's growth the wash from the tributary will build a delta, or fan, upon it, and this further growth will continue until the waters from the tributary valley have built up a suitable gradient for themselves across the flood-plain to the river. This only holds good in valleys of incompetent drainage which cannot cut and maintain a trench for themselves. If the tributary valley has a large, competent stream it will maintain a channel-way across the flood-plain to the river, and less aggradation will result from the shifting of the meanders, but that is not the case in hand.

If excuse for this academic statement is needed it is found in its special application to the case in hand; for either action of the kind just set forth is to be accepted as an elucidation of the case, as in the preferred interpretation that follows, or it is to be shown incompetent for such elucidation before we permit ourselves to go back of this action to earlier agencies. It is a vital principle of good practice that the agencies and phenomena nearest at hand be first considered, and, if the case requires, be eliminated, before recourse is had to more remote agencies. This is peculiarly true when, as in this case, the agencies closest at hand in time have quite certainly swept away the most of a more ancient record in making their own.

THE SPECIAL CASE.

The topographic environment of the relic-bearing deposit.—The site of the human remains is at the bottom of a small, short, rather steep-sided valley opening out on the flood-plain of the Missouri river. More specifically, the valley is less than a mile long, and less than half a mile wide, measured from crest to crest, and is about 160 feet deep at its mouth. The slopes on either hand are rather steep and nearly meet at a rather sharp angle in the axis of the valley, except that this is modified by the channel or dry run which forms narrow bottoms and little bluffs near the mouth,

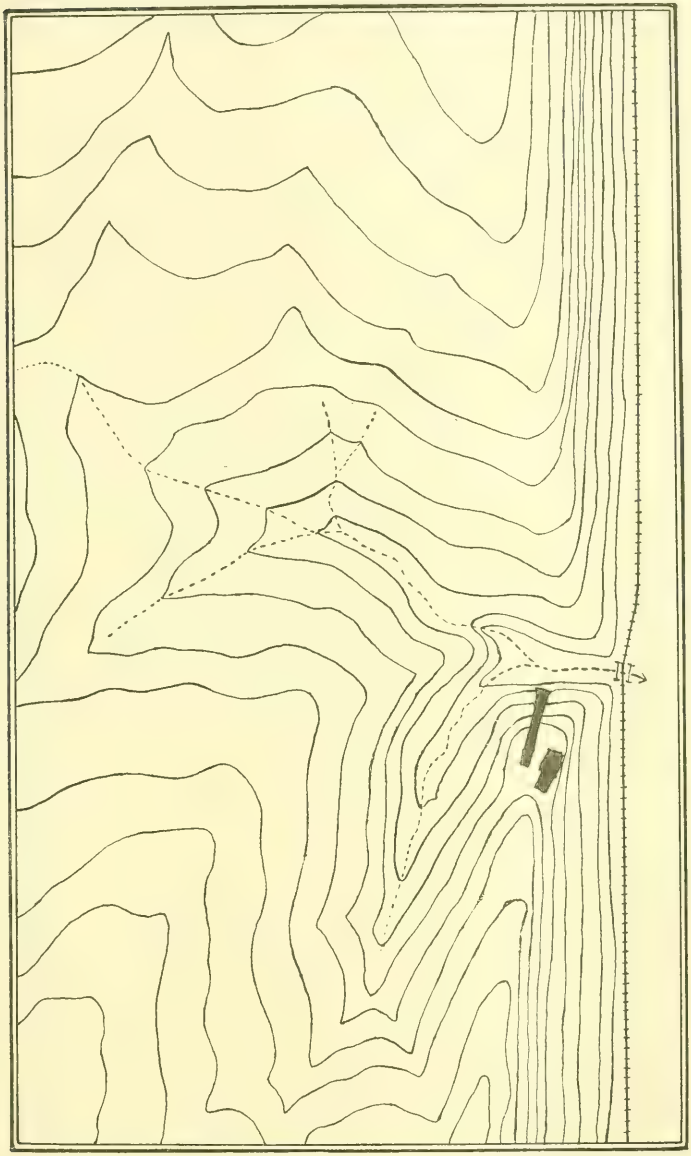


FIG. 4.—Topographic map of the tributary valley at Concannon's. From a sketch by Professor W. H. Holmes.

for the valley is not occupied by a permanent stream. The slope on the southward side is about as steep on the average as can be profitably cultivated; that on the north side is steeper, so that while the upper slope is cultivated the lower slope is left to natural growth and is partially occupied by quarries. On this steeper portion there are some small, vague, bench-like lines of uncertain interpretation; quite likely they are structural features dependent on the alternation of the more and the less resistant layers of the underlying strata. About twenty-five feet from the base of the slope there is an ill-defined bench that seems to be made up

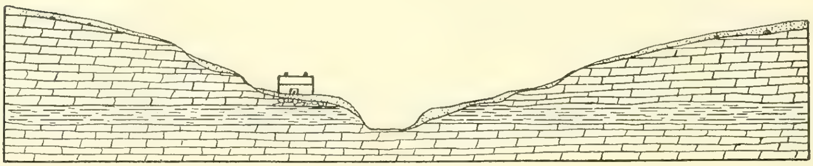


FIG. 5.—Section through the mouth of the tributary valley and the ridges on the north and south. Merely diagrammatic.

of lodgment matter adjusted to a former higher axis of the valley. There is a correspondingly vague bench on the opposite side. The ridges are composed of Carboniferous limestone, mantled by Pleistocene deposits (Fig. 5). The glacial drift is represented by some bowlders and smaller rubbish, but it is so scant and patchy as to be negligible as an element of the topography. The upland surface is mantled with loess and loam, the main portion of which is probably referable to the Iowan stage. The lower slopes are covered by wash from the uplands and by the skeleton-enclosing deposit which lies near the axis of the tributary valley and constitutes the vague benches above mentioned.

The back country is strongly rolling, the valleys fairly sharp, and their debouchures into the Missouri bottoms abrupt but well adjusted, and in their adjustments they represent the several normal types as well as several different stages. The bottoms of the Missouri are sharply defined by bluff faces. This is particularly so where the little valley in question joins it. The Missouri here runs southeastward, and the ridges bounding

the tributary valley on either side have been abruptly truncated by the waters of the Missouri and present a sharp talus face toward the bottoms. The recency of this face is a declared feature and is significant. Where not occupied by rock, the slope is formed of talus marked by slides and slump terraces so new as still to preserve their distinctive features. A very persistent slide terrace runs along the base of the south ridge at

FIG. 6.—View looking northward across the mouth of the tributary valley, showing Concannon's house at the left, and the truncated slope under it, the mouth of the valley just beyond, and in the center the north bluff with its truncated face overlooking the Missouri bottoms, on the edge of which the railroad lies. The bluff is about 160 feet high.

about the horizon of the skeleton's burial, ending nearly opposite it, and about ten rods distant. It is not intended here to suggest an immediate connection between this slide action and the burial of the relics, but merely to show the recency of the Missouri's work across the mouth of the tributary valley and within a few rods of the critical locality. This propinquity is brought into greater emphasis by noting that if a line be drawn from the crest of the talus slope of the north bluff to the crest

of the talus slope of the south bluff, it will run back of the skeleton's site. The significance of this close relation lies in the alternate depositional and aggradational work presumably done by the Missouri river at and in the mouth of the valley when it was truncating the adjacent bluffs on the one hand, and forming the adjacent bottoms on the other, in accordance with the principles of action outlined above. The accompanying contour map and photographs (Figs. 4 and 6–11), with their explanations, make these relations more definite.

The precise locality of the relics is more closely defined by an additional feature. A deep ravine starts near the crest of the ridge bounding the tributary valley on the south, and running nearly parallel with the truncated face overlooking the Missouri bottoms, joins the axis of the valley a few rods west of Concannon's house (see Fig. 7). East of this ravine there was doubtless once a round-back ridge of the usual erosion type with another ravine still to the eastward, but the encroachment of the Missouri has cut away the eastern half and substituted a steep talus slope. There now remains a sharp-edged spur descending toward the axis of the tributary valley, with a talus face on the side next the Missouri bottom, and a more gentle, yet rather steep slope to the ravine on the other side. Following down this sharp-edged spur, it is found to flatten somewhat for a few rods at about sixty feet above the bottom of the valley, much as though the flattened portion might be a remnant of a small terrace, structural or otherwise. Farther on, this breaks down, with rock exposure, for about ten feet to another flattening for another few rods. On this lower shoulder Mr. Concannon's house stands, beyond which the spur ends in a sharp descent of about thirty feet to the dry run of the valley. On the west side of the house the surface descends more gently to the ravine above described. It is under this westward slope, about one hundred feet back from the edge of the talus slope facing the Missouri bottoms, and about seventy feet southward from the little bluff facing the dry run of the valley, that the human remains were found buried about twenty feet deep. These details are given with some tediousness because they bear

upon the interpretation of the time and mode of deposition of the formation embracing the relics.

As already stated, the tributary valley is not occupied by a constant stream, but by periodic run-off. The channel at present is in a slightly aggraded and apparently still aggrading stage. It opens out upon the Missouri bottoms about two hundred feet

FIG. 7.—View of Concannon's house and environment seen from the south-southwest. In the foreground and center is the ravine leading down from the south, described in the text. The locality of the skeleton is nearly under the small white spot near the dark clump of trees on the slope at the left of the house. The ravine joins the tributary valley just at the left of this and the latter joins the Missouri bottoms in front of the house. The Missouri bottoms stretch across the upper part of the view, with the river (in its new course) and the opposite bluff in the extreme background.

from the locality of the relics, with perfect adjustment, and its recent deposits were slightly fanned out upon the bottoms of the main valley on our first visit, but had been largely washed onward by the rain that intervened before the second visit, illustrating the nature of the present adjustment. The depth of the

aggradation deposit is unknown to me, but it is probably not many feet, as the aggradation stage has but recently been inaugurated by the detour of the river. On the north side the spur next the Missouri bottoms grades down to this lower grada-

FIG. 8.—View from near the mouth of the tunnel looking northeastward across the bottom of the tributary valley, showing the gradation of the footslope of the north bluff into the Missouri bottoms seen at the right.

tion plain and the combination of lower slope and present bottom deposits is similar to that of an earlier date on the south side which contains the human bones (Fig. 8.)

The present aggrading washes have made a little bottom in the lower twenty rods of the valley, with meanders and little

bluffs where the loops bear against the older deposits of the valley. It is in the face of the little bluff on the south side, and about four feet above the valley bottom, that the mouth of the tunnel that disclosed the human remains is located. The base of the tunnel at its mouth is ten or twelve feet above the

Fig. 9.—View in the mouth of the tributary valley looking out upon the Missouri bottoms and showing the entrance to the tunnel at the extreme right. The material from the tunnel modifies the natural bottom, as seen in the foreground.

adjacent Missouri bottoms (Fig. 9). The lower four feet of the little bluff is formed of a thick bed of Carboniferous limestone; above this there is shale. The tunnel was started just above this limestone and driven back on its gently rising surface. It was carried by the Concannons seventy-two feet back from the face

of the bluff, and at its inner end its base is twenty-one feet five inches below the surface, an air-shaft permitting a tape-line measurement.

The relics found in excavating the tunnel represent an adult who had lost several teeth and a child whose teething stage, according to Professor Williston, implies an age of about nine

FIG. 10.—Front view of the skeleton of the adult and two of the associated bones, with the fragment of the child's jaw in the foreground. From a photograph furnished by Mr. M. C. Long.

years. The former is represented by a skull, femur, and other bones; the latter only by a fragment of a jaw (Fig. 10.) The bones of the adult are said to have been found near the inner end of the tunnel, and between one and two feet above its base. They were disarranged and at slightly different depths, but it is sufficient for present purposes to locate them at seventy feet from the entrance and twenty feet from the surface. The fragment of the child's jaw was found about sixty feet from the entrance and within a foot of the bottom of the tunnel. These statements relative to the discovery of the bones rest upon the testi-

mony of Michael T. and Joseph F. Concannon, who dug the tunnel. There is no ground to question their authenticity.

The associated deposit.—At the mouth of the tunnel the lower three or four feet of the deposit is composed mainly of limestone fragments and earthy débris, a part of the latter seeming to come from the Carboniferous beds, a part from the glacial drift or the loess, and a part from the river and valley wash ; in short, a rather heterogeneous mixture. Some parts are highly oxidized and iron-stained and some parts are relatively fresh and calcareous. At about three feet above the floor on the western side there is a definite layer of dark, highly calcareous clay less than three inches thick, but it does not appear on the opposite side. It is thinner in the inner portion of the tunnel, where the cross cut of Mr. Fowke shows that it rises on the west side and pinches out irregularly within a few feet. The upper part of the deposit at the entrance is a mottled silt of loess-loam aspect, containing occasional stony fragments. Its response to acid is irregular, sometimes giving no obvious effervescence, sometimes a feeble action, and sometimes a prompt and marked response. Sometimes the action is concentrated in definite spots, as though it came from a bit of limestone. The action is not that characteristic of typical loess. Even in the top of the tunnel some limestone fragments were seen seven or eight feet from its base. Even in the inner end of the tunnel the silt is notably mottled, in part irregularly, and in part in bands, more or less horizontal, as though controlled by stratification, though the staining is probably secondary. Acid tests indicated that calcareous matter is present, but that it is not abundant.

These observations were made on the tunnel as seen on our first visit. Under the direction of Professor Holmes, Mr. Gerard Fowke later made a series of supplementary excavations in different directions to develop the formation further and secure additional fossils. A full statement of the results will doubtless be given in Professor Holmes's report. He has kindly permitted me to use such of the data thus gathered as are serviceable in the geologic determinations. Without entering upon precise details, it will suffice here to say that the tunnel was extended

southward until the rising of the Carboniferous beds in the bottom made further extension in that direction unpromising. Only a few feet beyond the end of the original tunnel Carboniferous shale was found overlying the heavy stratum of limestone, and the surface of this rose as though the foot slope of the ridge had been reached. The correctness of this inference is scarcely open to question as the whole environment supports it so strongly that it had been anticipated. The ease with which this shale was eroded, compared with the underlying limestone, readily explains the flat limestone surface on which the tunnel was run.

In an excavation on the west side of the tunnel, a shallow trench was found in the upper surface of the limestone running nearly parallel with the tunnel and also parallel to the axis of the adjacent ravine. With little doubt this trench was the axis of the ravine in the erosion stage just preceding the filling up of the ravine by the relic-bearing deposit. This further aids in explaining the nearly horizontal, but slightly rising, base of the tunnel, since it locates it alongside the axis of the ravine on a resistant bed (see Fig. 13.)

An offset tunnel at right angles to the original tunnel was run eastward eleven feet from the place of the adult skeleton. It developed about four feet of disturbed shale and mixed débris in its base, the vague structure lines of which dipped eastward irregularly. It had the appearance of a talus slump that had crept down the slope of the adjacent rock surface, and warped and slightly tilted itself backwards according to a common habit of such masses. This doubtless took place before the upper deposit was laid upon it and while yet the ravine was open, *i. e.*, about the close of the erosion stage. In the east end of this offset, the silty formation has been slightly fissured along a nomber of lines by tensional action and the little crevices filled with a grayish-white soft deposit that effervesced very promptly with acid, implying calcium carbonate. The riveing tension probably came from the tendency of the mass to creep on the underlying rock surface, since this rises to the east and so furnishes a sloping base of shale which arrests the waters descending through

the more porous mass above and which, thus becoming wet, presents an unctuous slippery surface favorable to creep.

On the west side of the tunnel the excavation was carried from near the point where the fragment of the child's jaw was found westward at right angles and was met by an open cut from

FIG. 11.—View from the westward showing the trench dug by Mr. Fowke from the ravine toward the tunnel with which it connects below. The original tunnel runs from left to right under the two trees seen beyond the end of the cut. The child's jaw was found at the intersection of the cut (extended by tunnel below) with the original tunnel just at the left of the trees. The adult skeleton was found nearly under the second light spot to the right of the two trees.

the ravine. This open trench (Figs. 11 and 12) afforded an admirable opportunity to study the constitution and structure of the whole section from the rock floor to the surface through a depth of about twenty feet. The definite clayey band found near the base in the tunnel is here wanting. As noted above, it pinches

FIG. 12.—Nearer view of the open cut shown in Fig. 11. The shadow obscures the larger portion, but the lighted portion on the left shows the absence of definite stratification, and indicates something of the mottled character of the deposit.

out irregularly a short distance west of the original tunnel. Putting all the facts together, it would seem that this little stratum was laid down in the axis of the ravine shortly after the stage of aggradation began. As it scarcely reaches three inches in depth at its thickest point—averaging probably less than an inch—and is very homogeneous and peculiar, as well as very fresh and calcareous, it was probably formed at a single stage of inundation. Aside from this there is no distinct stratification or lamination in the whole section, nor any complete assortment of the material. The main material is a silt somewhat closely resembling loess, but unlike it in the particulars already pointed out. Through this silt, at all heights from the base to the surface, there are dispersed fragments of limestone, shale, and other débris incompatible with a typical loess deposit. The limestone fragments were sometimes several inches across. Mr. Fowke, who gave careful attention to the distribution of this material, affirms that it was found indifferently at all heights, and I carefully verified this by an examination of the walls of the deep open cut. Small fragments of softened limestone were so abundant in some parts that the walls were mottled with the white chalky spots made by the spade in mashing and spreading them. There were also many bits of shale ranging up to an inch in length, not a few of which had been sufficiently weathered to be yellowish or brownish. These also occurred high up as well as low down in the section.

I have said that there was no distinct stratification, lamination or assortment in the section. There was some aggregation of the silt and the fragmental material. There were spots where the shaly and limy débris was sufficiently abundant to lend a gravelly aspect to the mass, but close inspection showed that it was not really assorted, laminated, or stratified. The agency of accumulation had obviously brought relatively more fragmental débris to these portions, or at least had left relatively more fragmental débris in these portions, than in average portions, but the aggregation did not rise to the grade of typical assortment and lamination. That it is a wash product seems to me clear, but not a stream deposit nor a lake deposit, nor any other form of

purely subaqueous deposition. I should identify it as a typical aggradation deposit of the ravine and basal-slope type where the hillside environment was Carboniferous limestone and shale mantled with loess.

A few pebbles of drift and not a few pieces of charcoal were found in the section, the latter at different horizons. Many land shells and some additional bones were also found by Mr. Fowke, but no unios. These interesting features will doubtless be described in Professor Holmes's report.

As had been anticipated, the excavations show that the extent of the deposit is limited, and that it was penetrated by

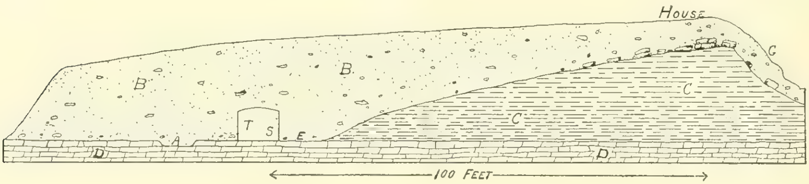


FIG. 13.—Cross-section from ravine at the left to truncated face overlooking the Missouri bottoms (G) on the right. The section passes through the end of the original tunnel (T) at the place of the adult skeleton (S). It shows the supposed original trench of the ravine in the surface of the limestone (A), the shale overlying the limestone, developed in the cistern and in the extension of the tunnel (C), the limestone blocks of the upper limestone under the house, and the deposit overlying the relics (B). The line marked 100 feet represents the distance from the place of the skeleton to the point where the truncated slope begins, not the whole length of the section.

the tunnel nearly or quite at its greatest depth. Rock comes to the surface just back of the house, and in the excavation for the rear end of the house, Mr. Concannon informed me that he reached rock which he thought was of the regular quarry kind. In sinking for a cistern eighteen feet deep on the east side of the house, he went through about four feet of dirt, then about two feet of loose limestone blocks, and then about twelve feet of "soapstone," so hard that he had to blast it. This is undoubtedly the Carboniferous shale encountered by Mr. Fowke in the extension of the tunnel. This makes it clear that the spur on which the house stands is formed mainly of Carboniferous beds and is merely mantled with the silt and débris formations. The accompanying cross-section is drawn approximately to a true

scale (Fig. 13) and shows the probable limitations of the deposit. The extension of the tunnel shows that it thins to the southward, while the ravine intercepts it on the west.

The surface configuration is that of a combined basal-slope and ravine-bottom deposit, *i. e.*, of aggradation in the bottom of the ravine, combined with deposits lodged on the lower slopes in adjustment to the aggraded bottom. The structure of the deposit is in keeping with this interpretation. The little layer of calcareous clay in the tunnel seems to imply deposition in standing, or slowly moving water, *i. e.*, a valley-bottom deposit, probably a back-water deposit. The absence otherwise of definite stratification or assortment of the material, and its complete resemblance to secondary slope accumulations derived jointly from the loess and the underlying beds seems to require its reference to aggradational action. Professor Williston found the cast of a clam shell with attached valves in the angle between the wall and the roof of the tunnel about seven feet from the base. In the absence of satisfactory evidences of fluvial action at this height and in the presence of human relics, this may well be referred to human agency.

INTERPRETATIONS.

The case is perhaps not an absolutely declared one, and a wholly unreserved interpretation may not be warranted, but a very strong balance of evidence seems to point in a specific direction. Certain things seem to me clear :

1. The deposit is not true original loess. It is a mixture of loess-like silt, Carboniferous detritus, water-laid clay and other débris. The Carboniferous detritus was obviously derived from the adjacent strata, in part by disintegration, in part by wear, and in part by fracture without much rounding. The loess-like silt was probably derived in the main by wash from the loess mantle of the adjacent hills, but in part also by winds from the Missouri bottoms ; possibly also in part by creep. Its character implies that some of the silt was brought to its present position without complete leaching, while most portions show evidences of exposure and weathering. From such differences

of history probably arose the variations in color, texture and effervescence in response to acid, which were observed. The material of the one distinctly water-laid layer was probably derived from the Carboniferous shales at some special stage of erosion and inundation — some unusual storm and flood, perhaps — and was deposited without weathering, and remained undisturbed except on its borders.

2. The truncated faces of the adjacent Missouri bluffs, and the numerous slides on these faces, show that the Missouri river has worked extensively and effectively across the mouth of the tributary only a few rods from the site of the relics, and that this has been comparatively recent.

The rather steep slopes of the tributary valley favor the view that the *present fashioning* of these is recent. The main excavation of the valley probably dates back to the post-Kansan erosion interval, and this was perhaps preceded, and perhaps determined, by a preglacial valley. But the valley, *as it is now fashioned*, is pretty closely adjusted to the Missouri river bottoms which are features of recent origin, and *this adjustment and the slopes and deposits involved in it* is, by rather strong presumption, to be connected with the development of the adjacent Missouri channel. The age of the original valley and of the upland mantles does not concern us here, unless these lower deposits, well down in the axis of the valley, and at its junction with the great river bottoms, are surely inheritances from the older period, and not adjustment phenomena.

3. The record of these earlier events is here very imperfect. Even the record of the more recent of the Pleistocene events is very scant where it should be abundant and decisive if the conditions of preservation had been favorable. In Dakota, where the Missouri river came into relation with the last stages of general glaciation within its basin, there are three great systems of terraces as worked out by Todd,[1] viz.: 1) "The higher bowldery terraces," varying from 500 feet to 350 feet above the Missouri and connected with the outer moraine of the Wisconsin stage; 2) "The lower bowldery terraces," varying from 350 feet to

[1] TODD, *Bull. U. S. Geol. Surv.*, No. 158, pp 128–154.

various lower levels at different points, and connected with the second moraine of the Wisconsin stage, and 3) a complex system of "silt terraces" ranging from 150 feet downward, three or four of these terraces often occurring at the same locality. These last have not been traced into physical continuity with any of the moraines, and doubtless represent in part the very latest stages of glaciation, and in larger part the postglacial stages ranging down to very recent times. A reference to Todd's descriptions will show that these are not mere strands or slender benches on the valley sides, but great platforms, sometimes a mile or two broad. Now all of these three systems, so magnificently developed in Dakota, should ideally be represented in some way at the Lansing locality, but we have only the obscure, sloping shoulders already described, and the little deposit containing the relics. There is no sign that these belong to the first or second of the Dakota series which are directly connected with the first and second stages of the Wisconsin glaciation. In Dakota these terraces are formed of very coarse material, which gives them the title "bowldery," and this implies strong currents fed by glacial débris. Normally, these high bowldery terraces should graduate down-stream into finer gravels, sands and silts, all bearing the distinctive marks of their glacio-fluvial origin. The relic-bearing deposit is not of this type, and is not overlain by this type. The most natural inference then is that the train of glacial gravels, sands and silts borne away by the Missouri waters from the ice edge in the more vigorous stages of Wisconsin glaciation was carried away from this part of the Missouri channel before the relic deposits were formed. This is the more to be supposed because the Missouri has here recently run hard against the highlands and truncated them, and the tributary valleys are steep and in this special case, short and rather sharp. Remnants of the true glacio-fluvial deposits in this portion of the Missouri river are rare, and an experienced Pleistocene geologist familiar with their habit would not expect to find them in the mouth of so narrow, steep-sided, and steep-bottomed a tributary as that at Concannon's. The probable reason for the scantiness of the glacio-fluvial record in this part

of the Missouri valley has been given in the preliminary considerations. If neither of the strong bowldery terraces of so late a stage of glaciation as the Wisconsin are represented at the site of the burial, there is but scant ground to assume that the earlier and much feebler and much more erosible glacio-fluvial deposits of the Iowan are preserved.

The natural conclusion is, therefore, that the little relic-bearing deposit in the valley at Concannon's belongs either to the same class as the silt terraces of Dakota, to which it bears a measure of resemblance, or to some later stage.

Specific views.— While, as before remarked, the case is perhaps not a wholly declared one, and an unqualified identification may not be entirely warranted, the range of tenable interpretation seems to me to lie within narrow limits.

1. *The most conservative and the most probable view.*— All the essential facts known to me seem to be explicable on the following lines which involve the minimum of action and of assumption, and which appeal only to the natural order of things. The first stage of essential action is assigned to a time when the channel of the Missouri river ran immediately past the mouth of the tributary valley and was higher than now to such an extent as to be in erosive adjustment with the tributary at the top of the rather heavy limestone layer which lies just below the tunnel. It has already been noted that where a strong stream like the Missouri passes hard by the mouth of such a tributary, two effective conditions of erosion are supplied. The tributary has a low point of discharge and hence a high gradient, and its detritus is immediately swept away by the great river. During this stage the rock surface under the relic-bearing deposit was developed by the removal of the shales above, and the lower slopes adjacent were measurably denuded because the conditions were favorable to erosion and the shales were easily cut away. After a stage of erosive adjustment of this kind, a change of relations was brought about by the diversion of the channel of the Missouri river to some other portion of the broad valley, attended by the substitution of a flood plain at the mouth of the tributary. As the vertical range of water is now twenty feet or more,

the building up of a normal upper flood plain that much above the preceding erosion plain may be assumed. This must have been accompanied by a filling up of the lower part of the tributary in like measure. More than this, if the diverted stream in its new course ran on the opposite side of the bottoms, two miles away, the tributary might have also built a fan on the surface of the flood plain, with proportional further aggradation within its mouth. Now this filling up of the axis of the valley to the amount indicated, changed the condition of the lower sides of the valley, and these became covered with lodgment deposits derived from the upper slopes and with silts blown up from the Missouri bottoms, an action still in effective operation. Such deposits are the normal result of an effort to establish a new set of gradients adjusted to a lifted axis. The deposit resulting from these combined agencies should be just such a mixed nondescript one as the actual case presents, viz., a little clear stratification in the lower part, some suggestion of stratification of an uncertain sort in the other portions, but no complete stratification or assortment; a general absence of declared structure, some limestone débris, some shale débris, a little drift, some loess wash, some soil wash, with land shells, some stream or back-water silt, with river shells — perhaps humanly introduced — and some wind silt; and hence, some portions unleached and others leached, with other variations from a typical unitarian deposit, such as true alluvium on the one hand, or typical loess on the other. It seems to me that the depth of the deposit is quite within the competency of this method, while its general configuration and aspect are in close accord with this interpretation. Under this view the burial of the human remains took place either during the latest phases the erosive process of the stage indicated, or in the early phase of the building of the flood plain. The antiquity of the burial is measured by the time occupied by the Missouri river in lowering its bottoms, two miles more or less in width, somewhere from fifteen to twenty-five feet, a very respectable antiquity, but much short of the close of the glacial invasion.

2. *Possible but not probable interpretations.*— As previously

indicated, the case is not so declared as to render a given interpretation wholly certain, and to absolutely exclude all others. While I think them quite improbable, other times and methods of burial may be entertained as within the bare limits of possibility.

1) As noted in the description, there are some small and obscure shoulders or terraces at different heights up to sixty feet above the upper flood plain of the Missouri river. It is not clear that the higher of these are anything but degradational inequalities of structural origin, but it may be worth while to recognize that these features may possibly be of fluvial origin, and may be genetically connected with the lower deposit containing the human relics, though there is no clear evidence of this. In this case the working level of the river must be placed at perhaps sixty feet above that of the present day, and its waters must be supposed to have invaded the mouth of the valley more extensively and deeply. The site of the relics is thus placed in the bottom of the ancient river, though not in its main channel. It was therefore, more or less subject to the scouring action of the river bottom, and to alternate deposition and removal, as set forth in the preliminary considerations. At any stage during such submersion, when the current of the river was directed against the mouth of the tributary, it would be theoretically possible for the pre-existing deposit to be scoured out and replaced in the manner so constantly illustrated by the present action of the river, and in connection with such removal and refilling, the relics could be introduced. This would place the time of their burial farther back, but probably not so far as even the latest stage of the last ice invasion.

The specific character of the deposit does not seem to me to lend support to this interpretation. It is not distinctly and specifically fluvial, as it might be expected to be if formed in the bottom of the river or in deep and constant water of any kind, It bears the aspect of a mixed combination product, such as postulated in the previous interpretation.

2) It may be held that the relics were buried in the early stages of the Wisconsin glaciation, when the Missouri river was

rising because of the filling of glacial wash poured into it at the north. In this case it would be assumed that the tributary valley had previously been fashioned as it is now, that with the filling up of the Missouri valley it also became filled in the lower part, involving the burial of the relics, and that with the lowering of the Missouri since the glacial period, it has been re-excavated to its present extent. In this case the filling should have combined the characters of a glacio-fluvial deposit and a back-water deposit. The actual deposit does not seem to me to be of this kind. The present adjustment of the tributary to the Missouri river must also, in this case, be regarded as an accident, however improbable.

3) It has been held by Upham and Winchell that the loess-like deposit covering the relics is a part of the sheet of loess that mantles the uplands of this region generally, and is referred to the Iowan stage of glaciation, and that the relics were buried in the early stages of this accumulation, or earlier. This view receives more apparent than real support from the partial resemblance of the upper part of the deposit to loess. As already stated, this does not seem to me to be true original loess, either of the upland or of the fluvial type, but a secondary deposit, in part, and only in part, derived from the loess. If so, its age is that of its derivation, not that of the parent loess. Very similar deposits seem to have been formed at all ages since the main loess epoch, and are being formed now, and apparently must continue to be formed as long as the general loess mantle remains the chief source of erosion and re-deposition, but these deposits generally betray their origin by their secondary characters, as in this case.

4) It is even possible to regard the limestone débris in which the skeleton was found as preglacial detritus, buried first by the Kansan drift, which was afterward eroded, and then by the loess-like deposit; but in the first place, the detritus is not of the distinctive residual surface type, since it is not thoroughly weathered and leached as such deposits usually are, and in the second place, the hypothesis assumes that the post-Kansan erosion was adjusted to the preglacial erosion with a degree of

nicety quite improbable, and in the third place, the view leaves very little erosion and deposition to be referred to the long, subsequent stages, and in the fourth place, it leaves the adjust, ment of the tributary to the Missouri a matter of accident, and two accidents of nice adjustment in one hypothesis are somewhat too many.

5) At the other extreme, it is perhaps possible to refer the burial to very modern action of the Missouri waters at a very exceptionally high stage, combined with deposition by the tributary, aided by slope wash and creep and wind work from the Missouri bottoms. This seems to me, however, to be pressing agencies to the limit of their possibilities rather than resting with their probabilities within the limits of their more habitual action.

Without holding it to be quite demonstrable, it seems to me that the weight of evidence is very strong in favor of the first and most conservative interpretation, which finds an apt and adequate explanation in the natural order of things.

In this connection, I beg to invite the attention of archæologists to the slight grounds for hope of finding really strong evidences of man's antiquity in the fluvial deposits of the glacial rivers, because of the liability of these deposits to deep overworking by scour-and-fill. On the Ohio, for example, the floods are today boring out deep holes in the river and shortly filling these again, only to bore and fill somewhere else. It would doubtless not be difficult to sow coins of this year's mint over the bottom of this river in such a way that a decade hence they would be buried a score or some scores of feet in gravel and sand ; and what is more, this gravel and sand would be of the glacio-fluvial type, since it would be only the true glacio-fluvial material rearranged by stream action not unlike that which originally formed it. It would hence be stratified, and nearly or quite indistinguishable in small sections from the original. The same process has been in progress ever since the river began to erode the glacial filling. If its early meanders covered the whole of the original glacial flood plain, no part of it would be exempt from the suspicion of such overworking and natural intrusion.

It thus appears that even if the burying gravels were of glacial aspect, and the burial were a score or two score, or perhaps even three or four score feet deep, it would require careful circumspection to remove legitimate and necessary doubts arising from this source. This might be done in special cases on geologic grounds, and the nature of the human deposit might in other cases help to eliminate these sources of doubt, but special and strong evidence of this kind is required to make a good case.

So far as the glacial ages are concerned, evidence of man's presence should be sought rather in the interglacial than in the equivocal fluvial deposits. With careful identification and reasonable circumspection, all sources of doubt as to age could be removed from the intercalated deposits of the interglacial epochs, and as these carry the relics of other life, they are competent to carry those of man if he really lived in the region at the time.

I am permitted to add the following notes by Professor Calvin and Professor Salisbury, who examined the deposit with me, and who have been kind enough to read and criticise my manuscript, as prepared before my second visit. The observations of that visit strengthened the grounds on which they have indicated slight divergencies from my views.

T. C. Chamberlin.

STATEMENT OF PROFESSOR CALVIN.

I thank you for the opportunity you have given me to read the manuscript of your paper on "The Geologic Relations of the Human Relics of Lansing, Kan." I wish to thank you further, not for myself alone, but on behalf of all geologists engaged in the study of problems similar to the one under discussion, for the full and clear presentation of the behavior of rivers of the Missouri type in connection with migrations of their meanders, of their work in degradation and aggradation, in scour-and-fill, while deepening and widening their valleys, and of the changing conditions which they impose on their tributaries. The application of the principles discussed in the preliminary part

of the paper to the interpretation of the deposit in which the human bones were found near Lansing, Kan., as given in your Interpretation 1, seems to fit the case and harmonize all the facts in a very admirable way. If I were to dissent at all from your conclusions as stated in Interpretation 1, it would simply be to the extent of saying that a lowering of the Missouri valley since the bones and associated silts were deposited, through a space somewhat less than fifteen or twenty-five feet, would probably be amply sufficient.

SAMUEL CALVIN.

STATEMENT OF PROFESSOR SALISBURY.

With the general conclusion of the above paper as expressed under the heading, "The most conservative and the most probable view," I am in perfect accord. If I have any suggestions to add, they are the following:

1. Aside from the distinct layer of clay in one wall of the tunnel, I saw no structure which could properly be called stratification.

2. The band of water-laid clay seemed to me to imply stagnant or essentially stagnant water. I am disposed to refer its origin to a time when high water in the Missouri ponded the tributary. Since the level of the clay is but a few feet above the historic high-water mark of the river, the stream need not have been flowing more than a few feet above its present level when the clay was deposited. I see no reason for supposing that the introduction of the skeleton and the deposition of the clay were far separated in time.

3. The unequivocal layer of water-laid clay seems to me strong evidence against the view that the material in which it occurs is referable to any of the recognized loess epochs. I have seen thousands of sections of loess, but never one with such a seam of clay.

4. I regard the presence of the unio shell as evidence that the loess in which the tunnel is dug is not in its original posi-

tion. I am not aware that a unio shell has ever been found in undisturbed loess. The presence of the shell in *loess talus*—for that seems to me the proper characterization of the material in which the human relics were found—could be readily accounted for in various ways, one of which is suggested in the preceding pages.

ROLLIN D. SALISBURY.

Studies for Students

THE MAPPING OF THE CRYSTALLINE SCHISTS.

PART I.—METHODS.

INTRODUCTION.

CONVENTIONAL GEOLOGICAL MAPS A MIXTURE OF FACT AND THEORY IN UNKNOWN PROPORTIONS.—For areas of the crystalline schists no person save the maker or some one familiar with the area represented, can form any estimate of the value of a geological map. In proportions dependent not alone upon the worker and his conditions, but upon the area itself, theory has been compounded with fact, until the map represents not what is, but what the maker thinks after a study more or less extended. Unfortunate also it is that the thoroughness and detail of the study is not revealed. It is true that a geological map may be so constructed as to disclose at once an impossible condition, or one so contrary to common experience as to excite suspicion, so that von Decken, the greatest of German map makers, once said that there were really but two classes of geological maps—those that may be right and those that cannot be right. But on the other hand, a map may be prepared with but little examination upon the ground, which is quite as plausible in aspect, or it may be even more plausible, than one prepared by a conscientious and

competent worker who at great expense of labor and thought visits each exposure and studies it with respect to all its neighbors.

In regions in which rock types are easily distinguished, and where the tectonic structure is simple, the difficulties above referred to are reduced to a minimum; but in belts in which the rocks have been profoundly metamorphosed, and where orographic forces have brought about a complex structure, the dangers which arise from compounding fact and theory may be so great as to practically destroy the value of the map.

Outcrop maps needed to display the fact.— The largest element of danger is removed and a map increased very much in value by indicating upon the tinted areas of the different formations (the theory) the position, the nature and the observed peculiarities of the outcroppings (the fact). If a map has been made without sufficient field study this fact will then appear, and if it must be more thoroughly worked out and republished, the earlier work is not lost if it was intelligently and conscientiously done. If, however, it was carelessly, or for any reason inefficiently done, the examination of a few of the exposures which have been represented upon the map will supply the basis for judgment. In a complex area much time is consumed in making a just estimate of the value of a conventional geological map, and if revision is necessary the work must be taken up *de novo*, even if the field work was efficient so far as it was carried.

The serious objection to the general use of outcrop maps is, of course, the great expense which they involve because of the large scale which must be adopted. In the complex region bordering Lake Superior, the United States geological survey has most wisely adopted the plan of publishing outcrop maps to properly present the careful work of the geologists of the division. It is safe to say that the time is not far distant when equally precise methods must be adopted at least by government and state institutions for all regions of equal or of greater complexity.

FACT.—THE OBSERVATIONS.

Routine field observations.—*Location of outcrops.*—The first requisite for geological mapping in a region of crystalline

rocks, is an accurate base map of sufficiently large scale. Unless the relief is slight or the topography of a simple character, it is essential that the topography be represented either by hachures or contours, preferably the latter. A scale of an inch to the mile (1 : 62,500) with a contour interval of twenty feet will no more than suffice to express the detail that is necessary for the best results. If roads are numerous and reasonably good, a bicycle with cyclometer attachment will be a valuable adjunct, and with little doubt the best way of securing base locations as well as getting quickly from place to place.[1]

By the use of the aneroid and 4-inch sighting compass, and by pacing, all locations can probably be made with sufficient accuracy if the base map is reasonably good and the country is one of diversified topography. In a wilderness like that about Lake Superior, where the monotonous uniformity of the topography and the forest cover make outlook impossible, the matter of location becomes exceedingly difficult. The problem has there been solved by scouring the country for outcrops in parallel and contiguous belts, a compassman accompanying each geologist to keep the direction and pace the distance, so as to allow him some freedom of movement.

Examination of rock and collection of specimens.—The examination of the rock is made upon the ground after securing the freshly broken surface of a specimen as little weathered as possible.

The specimen should be examined with the naked eye for its general aspect and compared with the weathered surface of the outcrop. Its manner of fracturing under the hammer may be of much significance, and of two closely similar rocks it may even remain the chief distinguishing difference in the field observation. With a pocket lens of a magnification of 6–14 diameters, according to personal preference,[2] a more careful examination is made of the fresh surface to note the essential and accessory minerals and their relative proportions, the texture

[1] HOBBS, "The Geologist Awheel," *Pop. Sci. Month.*, Vol. LVIII, pp. 515–518.

[2] The best lenses for the purpose are the Hastings aplanatic triplets, manufactured by Bausch & Lomb, Rochester, N. Y.

of the rock, the evidence of crushing, etc. A specimen of the fresh rock, in case the type is new to the region or of doubtful determination, is made by trimming a fragment into the shape of an elongated rectangular pillow three by four inches and of a maximum thickness of an inch. One or more chips for section cutting are also collected. When determinations are extremely difficult a series of smaller specimens untrimmed and showing the weathered as well as the fresh surfaces will be found far more valuable for identification and reference. These to the number of ten or more and representing as different phases as possible may be chipped from a single exposure or from near-lying exposures and given a single number as a series.

Measurement of strike and dip.— It is a time-honored and almost uniform practice to record the present direction of the plane of bedding in terms of the strike (the direction of the water line if the outcrop were partially submerged) and the dip (its inclination normal to the strike). Both these terms have a definite meaning when applied to the only slightly disturbed sedimentary rocks, and may properly be measured by the text-book methods, the former by leveling the compass with its north-south edge in contact with the bedding plane and reading the bearing, the latter by taking the steepest inclination of the beds — the one normal to the strike.

In the crystalline schist areas, however, the matter is far from simple. The rock may have no definite structure plane, either because of igneous origin or from metamorphism of a bedded rock. Again it may show one or more prominent structures, but no one of them may represent the plane of sedimentation. If one of them is proven to be the plane of bedding the best determination of the strike would probably not be obtained by the text-book method of placing the compass edge in contact with the rock surface. A quicker and generally more correct method is to hold the compass above or beside the exposure and adjust it by the eye to correspond to the average strike of the exposure. The error of the eye in adjusting to parallelism, which should hardly exceed 5°, is inconsiderable when the variation between different parts of an exposure or between near-lying exposures is taken into account.

Something further will be said upon the differentiation of original and secondary structures

IMPORTANT ADDITIONAL OBSERVATIONS.—*Pitch and its measurement.*—Hardly less important than the inclination of the bedding plane at a locality is the pitch of the folds—the inclination of their trough and crest lines. Vital as is this element in the determination of the structure of an area, it is only in recent years that it has been given much weight in field investigations. It is safe to say that its importance is yet only half appreciated. To Professor Raphael Pumpelly, who directed the early field work in the New England area, is due the credit of bringing to the front this element in the field study of crystalline rocks. The details regarding the methods of measuring it were worked out by the assistants in his division.[1]

The pitch is often consciously or unconsciously measured as a component element of the dip, the dip being increasingly determined by the pitch as the outcrop is near the crest or the trough of a fold. Pitch can only be measured at the locality when the outcrop exhibits minor folds or plications, the study of the Green Mountains having clearly demonstrated the fact that the minor fold is the epitome of the major fold. The pitch is subject to the same kind of variations within an exposure as is the dip, and it must not be recorded from a single minor fold or plication without first noting whether other folds or plications give similar values. Even then its inclination cannot fairly be assumed beyond the exposure itself, and it is only by examination of a series of exposures that a *persistent pitch* is determined.

When not to be made out at an exposure, pitch (and here a persistent one) is correctly inferred when the strikes of the opposite limbs of a fold are other than parallel. A syncline pitches in the direction in which the strikes of its opposite limbs diverge and an anticline in the direction in which they converge.

Inferences regarding the pitch may often be drawn from the profiles of ridges, the gradually sloping lines being formed by the crests of folds.

[1] See *Monograph XXIII, U. S. Geol. Surv.;* also VAN HISE, "Principles of Pre-Cambrian Geology," *Sixteenth Ann. Report U. S. Geol. Surv.*, Part I, 1896, pp. 603–632.

SECONDARY FOLIATION AND BANDING IN GNEISS ON STATE ROAD NEAR GREAT BARRINGTON, MASS.

The direction of the original plane of bedding is now nearly horizontal as indicated by the lines of crumpled quartz lenses near the top and bottom of the exposure. The secondary foliation and banding appear at the left and between the crumpled rows of quartz lenses.

Van Hise has shown that the crests of folds are lines of special importance by reason of the fact that the order of superposition of beds is there almost sure to be the normal one, and the additional fact that crushing being there at a minimum, conglomeratic and other original structures are most likely to be preserved.

Form of minor folds.— As might be inferred from the last section, the form of the minor fold or the plication is full of meaning respecting the characteristics of the larger folds of the region, and it should, therefore, be carefully studied and its peculiarities sketched or recorded.

Secondary foliation and its relation to bedding.— Foliation is one of the commonest of the structures in the crystalline schists. It is now well known that in the recent past the strike and dip of foliation have rather generally been measured as those of bedding, so that in most papers, written more than a decade since, the secondary nature of foliation was not recognized, and recorded observations of dip and strike as frequently refer to secondary foliation as to planes of sedimentation. Even with the larger knowledge of the present, the differentiation of the two structures is difficult and often impossible. Two, three, or even more sets of planes of separation, with widely different directions, may all be easily made out in the same hand specimen of clastic rock, and yet no one of them correspond in direction with the bedding plane.

A difference in composition characterizing alternate parallel bands of considerable thickness is undoubtedly the best criterion for determining the plane of sedimentation.[1] A striking instance of secondary banding is represented in Plate I, where the bedding plane is outlined by the crumpled lenses of quartz and by even more beautiful puckered bandings not discernible in the view. The secondary straight banding is parallel to the foliation. (Plate XIV of the work last cited is from near this locality.) Such a structure, or one resembling it, may, however, be produced by the mashing of a coarse granite or conglomer-

[1] See, however, HOBBS, "Secondary Banding in Gneiss," *Bull. Geol. Soc. Am.*, Vol. III, pp. 460–464, Pl. XIV.

ate, but the characteristic structures of these rocks are usually not obliterated unless the bands are reduced to a thickness of a quarter of an inch or less. Again injection of granitic material along the planes of foliation of a rock may produce an alternation of bands of different composition. Such a structure is, however, apt to be recognized by an experienced observer, and unless subsequently mashed the bands are not sufficiently uniform in thickness to simulate bedding.

Of all the crystalline rock types of clastic origin, quartzite offers the greatest difficulties in the search for the bedding plane. In fact, it is generally impossible to determine it except by contacts with other formations.

Other things being equal, the more crenulated or wavy a structure, the greater the probability that it is original. Also the more its general direction diverges from an undisturbed plane of foliation the more likelihood is there that it is earlier and original. When the bedding plane cannot be made out with certainty at a particular locality it may sometimes be inferred from a study of the form of the minor folds in their relation to foliation at a neighboring locality. Owing to the fact that mashing is at a minimum in the arches of folds, careful search in an area of closely compressed folding will often reveal at regular intervals the beautifully crenulated arches with foliation planes bisecting them, although between such localities the foliation planes only can be found. Such a method may even be applied to a slate. The green and purple slates of the Taconic range of mountains dip to the eastward persistently and quite uniformly. The writer was able to find at fairly regular intervals across the strike of this foliation the acute crests of easterly dipping anticlines preserved in lenses of infiltrated silica, thus showing that a series of moderate thickness has, by buckling and compression, brought about perfect foliation parallel to the axial planes of the folds, and thus given the impression of vast thickness.

Van Hise, in his treatment of the mechanics of flexuring—confirmed by field observation—has shown that in moderately compressed folds the foliation planes of the opposite

limbs converge downward in an anticline and upward in a syncline.[1]

Joint planes.—Joint planes more or less perfectly developed are almost universally present in the crystalline rocks. They are planes of separation in parallel series, of which more than one is usually to be made out. They usually have a very steep inclination and are probably like the folding, in most cases a result of the compression of the area. Their number (*i. e.*, the number of series) and relative perfection, and the direction and inclination of their walls, should be carefully noted, with the relation of these to lines of displacement and to topographic features.

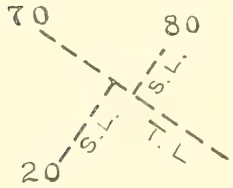
Scarps and steep rock walls.—Little attention seems to have been accorded these features of rock exposures. In the sequel I propose to show their importance in the geological structure of a region. Their direction and magnitude should be noted, and if possible some symbol easily distinguished from the dip and strike symbol should be entered at least upon the working map. A short dotted line will serve to indicate the direction of the scarps and a figure at its end its bearing to the east or west of north.

Margin of outcrop.—Another neglected feature of rock exposures is the margin of the outcropping. Every experienced geologist must be able to recall numerous instances where outcrops, grouped so thickly as to indicate probably but slight covering in the intervening area, cease abruptly at a border which is often nearly or quite rectilinear and perhaps is also for sections of its extension the margin of individual exposures. Such observations, it is believed, are of great significance in the proper interpretation of the structure of a region.

Gorges and sharp straight valleys.—Even the best of the topographical maps do not indicate all gorges or rectilinear valleys with rock walls. In the interpretation of the geological structure their significance may be considerable, and it is important to note their direction and in many cases also the height of their

[1] See on the general subject of foliation, PUMPELLY, WOLFF and DALE, *Monograph* XXIII; *U. S. Geol. Surv.*, pp. 136–158, Pt. I, 1896; and VAN HISE, *Sixteenth Ann. Report U. S. Geol. Surv.*, Pt. I, pp. 633–668.

walls. A symbol like the cut will be found useful in recording them upon the map. The figure at the end of the trough line of the valley indicates the bearing in degrees to the east or west of north, as the case may be. The slope lines on either side pointed toward the trough are like Dana's dip symbols adjusted



in length to indicate the steepness of the slope, a large slope line indicating a gentler slope. The figures used in connection with these lines indicate the height in feet of the walls on either side, an estimate being expressed by the ± sign. Very large and important valleys are often omitted from topographic maps the topography of which is sketched, because hidden from points at which the sketches were taken.

Nature of contact surface of formations.—Contacts of formations wherever exposed should be carefully scrutinized, not only to discover evidence of conformity or unconformity, but for indication of slipping, thrusting or faulting. The contact plane of formations for two reasons is likely to be a locus of displacement. In the first place contacts are likely to be planes of weakness where a maximum of movement has occurred ; and in the second place, displacement, whether by normal faulting or thrusting, produces new contacts. It is, therefore, to be noted at the contact of sedimentary formations : first, whether the plane of contact is the natural result of sedimentation, and whether conformable or not ; second, whether the deformation of the contact plane, if present, is such as may be explained by accommodation of layers in flexuring, or must be accounted for by the more violent processes of normal faulting or thrust. With good exposures the direction of the plane of displacement will probably allow of a decision between thrusting and normal faulting. If insufficiently exposed the nature of the folding and the general character of the deformation within the area may afford a clue. Both normal faulting and thrusting may, however, have occurred at the same contact.

THEORY.— THE DRAWING OF BOUNDARIES AND COLORING OF MAP.

THE CANONS OF GEOLOGICAL MAPPING FOR THE CRYSTALLINE AREAS. —The determination of what types of rock shall be grouped under one formation-color may be a problem of the greatest difficulty, but in the absence of conglomerates or clearly marked unconformities, the question is a petrological one to be settled by the best judgment of the observer on the ground checked by subsequent microsopical and perhaps chemical investigation in the laboratory. Where the contacts are not sharp but exhibit gradational facies, there may be a question as to where the dividing surface should be fixed, but this is after all a matter of comparatively small moment, and however determined, there is little danger that much violence will be done the facts.

The drawing of boundaries where contacts are not exposed—and contacts are generally covered—is a problem calling not only for much judgment but often also for a large imagination. In most domains of science the worker is allowed to express his lack of adequate data upon which to base a conclusion, and to reserve his judgment pending the obtaining of fuller information. Here, however, the demand is peremptory and the line must be drawn with or without knowledge. It is no uncommon experience to find within a region of intricate geological structure an alluvial valley a mile or more in width bordered by drift mantles of only lesser width before the bed rock is exposed. However the boundary lines of the formations are drawn, the map maker may be reasonably sure of one fact only,—that the reality is totally different from the representation. Convention requires that all areas shall be colored to show the underlying rock, and it may at least be said that the result is every whit as attractive and plausible in appearance as though the coloring were based throughout upon observed facts.

It is perhaps a step in the right direction to leave the lakes and rivers uncolored, as is now done by the United States geological survey upon its atlas sheets; but to this also there are serious objections, as, for example, in the area about New York city, where the numerous bridges, piers and abutments, tun-

nels, and government dredgings afford a body of knowledge of the submarine bed rock equal to that obtainable from most land areas.

The necessity for drawing boundaries in covered areas has evolved a body of largely unwritten doctrine which may not inaptly be referred to as the canons of geological mapping for the crystalline areas. Some of these canons are truths, others half truths, and still others have little basis in fact. Some of the more important of them are subjoined with brief critical notes. They are of course to be weighed in connection with one another and a compromise decided upon.

1. *Propinquity of outcrop.—Near-lying outcrops should be connected when not separated by outcrops of a different formation.* This rule is almost axiomatic and thoroughly sound in principle provided no contrary evidence is at hand; but there is yet a possibility of error even when outcrops are separated by less than one hundred feet.

2. *Contacts covered.—The boundary is not at the margin of either of the separated outcrops of different formations, but at some line between.* This is a general rule but with many exceptions.

3. *Strike.—Direction of boundary conforms to strike of near outcrops.* A rule of much value but to be weighed with other considerations before decision is made.

4. *Slopes.—On slopes boundaries should be corrected for strike and dip.* With vertical beds if the strike is away from the elevation in the general direction in which the boundary is being extended, the boundary will run down the slope, if toward the elevation it will run up the slope. If the slope also changes in such manner that the contour line converges less or diverges more from the strike the boundary will curve more rapidly down the slope; if the contours diverge less from or converge more with the strike in that same direction, the boundaries will the more rapidly ascend the slope. If the dip is with the elevation the boundary bends the more up the slope, if out from the elevation the more down the slope.

5. *Topographic breaks.—Sudden changes in slope not caused by talus or drift are likely to correspond to contacts.*

6. *Variable hardness of rock.— Ridges are occupied by harder rock, valleys by softer or more soluble rock.* To be applied with great caution. In many districts, in the opinion of the writer, the valleys are nearly if not quite as often hard as soft rock. A structural line of weakness may have produced a pre-glacial stream bed which the ice-cap widened and deepened; an antecedent stream may have produced the same result in hard rocks, an orographic block may have suffered depression, etc.

7. *Hydrography.—In a limestone and hard rock country lakes, ponds, rivers, and swamps are generally in softer or more soluble rock.* A most pernicious doctrine because so generally accepted and so frequently wrong. Faith in the canon also discourages investigation. The writer has in mind a nearly circular lake in the middle of a great valley largely underlaid by limestone, but about one-half the lake bottom is mica schist, the other half limestone.

8. *Ridge and valley structure.— Ridges are more generally synclines and valleys anticlines.* A half truth. It is perhaps true in the greater number of instances of rocks which suffer an amount of plication and rupturing of flexures (schists, slates, and sometimes limestones). It is not true of the heavy gneisses which so generally raise their heads in domes, the beds quite generally dipping with the slopes.

9. *Blocks.— Angular blocks when not lying on steep slopes and not clearly ice borne are on bed rock of the same kind.* The tendency is to drive this doctrine to its limit. For great limestone blocks not strengthened by silica or silicates it may perhaps be assumed that they are not very far from the parent ledge. With a framework of silica they have been carried by the ice thirty miles or more.

10. *Sink-hole structure.— Superficially undrained areas when not morainal (or in drift) are on limestone.* A pretty safe rule.

11. *Soil.—In a limestone and hard rock country arable farm land is on limestone and woodland on hard rock.* A fairly useful rule if applied intelligently.

Canons of mapping modified by basal assumptions.—The above canons are to be considered in connection with one

another, the worker giving to each what weight in his judgment is best to secure a compromise for the result. They are perhaps as good a set of rules as we can secure for the settlement of matters regarding which the known facts are insufficient to allow of a definitive conclusion.

A map constructed upon observations and rules as above outlined might be difficult to read, as the order of superposition of the formations might not at once be clear. The formations do not always appear upon the map in their direct order, being sometimes inverted, and sometimes individual formations do not lie next to their immediate neighbors above and below. The map maker is expected to show how each formation has been brought into its present positions and attitudes, to do which fundamental assumptions of far-reaching importance are made Theory is thereby brought in very large measure into the solution of the problem, it may be so as to take precedence over the canons of doctrine which have been outlined above. These basal assumptions and their effect upon the map will be considered in a second paper.

WILLIAM HERBERT HOBBS.

EDITORIAL.

THE discovery of human remains under twenty feet of débris near Lansing, Kan., has revived interest in the antiquity of man in America, and fortunately on more hopeful lines than hereto fore, since the mode of occurrence at Lansing is more definitely determinate than in most previous cases of the kind, and the geologic elements of the problem are more declared, though, as it happens, they belong to a much overlooked yet very common type. The recent studies of Brower and Winchell on the quartz chips at Little Falls have brought that case into more definite form.

There remain about the same differences of interpretation as heretofore, but these will pass away as the specific identification of glacio-fluvial, alluvial, and sub-aërial adjustment deposits becomes more familiar and precise, and as their interpretation is at once given greater latitude and made more strictly dependent on discriminative criteria.

In the judgment of the writer, neither of the above cases affords any substantial ground for affirming the presence of man in America during the glacial period; but they do afford a strong presumption that man in this country has witnessed very notable progress in the deepening of the channels of the Missouri and Mississippi rivers. In time there may be found means for estimating the rate at which these rivers are lowering their channels, but at present these are wanting, and there is no trustworthy method of estimating in years the time consumed in the deepening which has taken place since the human relics were buried.

T. C. C.

Reviews

Kakabikansing. By J. V. Brower. St. Paul, Minn.: H. L. Collins & Co.

Under this bizarre title Mr. Brower has described the occurrence of quartz chippings at Little Falls, Minn., prefixing a sketch of the previous studies of Winchell, Babbitt, Upham, Hill, Holmes, and Hershey, and affixing a letter from Professor Winchell and a statement on "Primitive Man in the Ice Age" by Mr. Warren Upham. The descriptions of Mr. Brower are apparently careful and candid, so far as intention goes, but they are obviously not those of a critical geological observer. They neglect most of the really discriminative factors and embrace much inconsequential matter. Notably also they have the trait, so common to the untrained worker, of incorporating interpretation unconsciously while insisting on "ascertained facts." "The glacial river" plays a notable part in the description of the formations, whereas the very thing to be demonstrated is the "glacial" or non-glacial character of the river at the time the formations in question were made. None the less the excellent photographs and the maps, together with the statement of Professor Winchell, largely supply the lacking data and make it possible to consider whether the interpretations put upon them are the normal ones or not.

From these it appears that there overspreads the plain once occupied by the Mississippi waters, but now above their reach, a surface layer of dirty pebbly sand of the typical structureless kind which usually covers abandoned flood plains of sand and gravel. This is about four feet thick and at places near the river contains many chips of white vein quartz of undoubted human origin. The source of the quartz is unquestionably the veins in the outcropping slate over which the falls are formed. This quartz-bearing slate does not now rise as high as the upper surface of the plain, and this fact has been urged by Holmes and Hershey as evidence that the quartz chippings were not taken from the parent ledge until the plain had been cut down to the requisite depth after its original completion. Mr. Brower, while not answering this objection by positive evidence, holds that the crest of the quartz-bearing ledge was exposed at seasons of low water, though

covered at times of flood. It is of course probable that the crest of the ledge has been worn down where the river flows over it, but such erosive covering by the river does not fit in well with the view that this same portion was the source whence large quantities of vein quartz were quarried at the same time. It is clearly urging a bare possibility at best rather than a probable occurrence.

If, however, the case rested merely on the possibility of reaching the source of the quartz while yet the uppermost layers of the original plain were in the process of formation, it might be ungenerous to refuse to entertain the utmost possibilities of the case in favor of glacial man in America. But the facts of the case, taken just as given in this paper, do not seem to the reviewer to afford even a plausible ground for assigning the quartz chips to the glacial stage of the river. The surface deposit in which they are found, as described and illustrated in the paper, not only does not bear the characteristics of a glacio-fluvial deposit, but bears quite clear evidence that it is not glacio-fluvial. The descriptions cite the fact that the surface deposit is highest near the bank of the present bottoms, after the common habit of existing degrading rivers. This habit is recognized and the facts are summarized in the following quotation (p. 73): "At Little Falls, Minn., the eastern portion of the sandy plain on the east side of the Mississippi is several feet lower than the crest of the plain at the east end of the dam. That fact is important. After the great glacial river which overspread the entire plain at Little Falls had withdrawn into the narrower limits of an eroded streambed, that river, often in freshet from the effects of the melting ice-sheet, occasionally re-overflowed the entire plain, disturbing and overturning the sandy surface, mixing into its materials every chipped quartz blade or spall which had been placed by the hand of man upon the surface adjoining the newly eroded and narrower channel. The higher altitudes of the plain along the Mississippi between 'The Notch' and the dam were caused by successive stages of recurring overflowage, creating additional surface deposits upon the plain nearest to the newly formed river bank." This is indeed "important," as the author himself naïvely remarks, since it shows, as the author also recognizes with equal unconsciousness of its real meaning, that it is the characteristic action of streams of *the present non-glacial régime*. It is here recognized, with undoubted correctness, that the quartzes were buried "by disturbing and overturning the sandy surface" and by "additional surface deposits." The reference of this, however, to *glacial* waters is

wholly without evidence and quite against the probabilities. Glacial streams as a rule have the aggrading habit, and are not therefore "withdrawn into the narrower limits of an eroded streambed," but on the contrary, are constantly shifting their courses from one point to another across their whole plain. Usually they subdivide into a complex plexus of numerous shallow shifting branches. There is therefore no reason whatever to suppose that the present channel of the Mississippi at Little Falls was in existence, even in its initial stages, while the river remained truly a glacial stream. The fact that the relic-bearing deposit is closely related to the present stream is *evidence that it was postglacial.* The deposit that carries the relics supports the same view, for it bears the characteristics of a postglacial rather a glacial formation. On the evidence submitted, therefore, in the paper the inference is rather imperative that the quartz chips were buried at some stage when postglacial rather than glacial conditions prevailed. To make this more clear, it may be worth while to sketch the normal succession of events and to gather from these the normal interpretation of the time and mode of burial of the quartz chips, assuming, as everywhere throughout this review, the complete trustworthiness of the evidence given in the paper, especially that afforded by its excellent photographic illustrations.

1. During the time the glacial border lay across the sources of the Mississippi and it was therefore truly a glacial stream, the normal inference is that it had the aggrading habit because of its overburden of glacial detritus; that it took the form of a plexus of numerous branchlets, and that it occupied, by the constant shifting of these, the whole plain which it was engaged in building up. In the nature of the case it should normally have no fixed channel nor any permanent flood plain deposit, since its whole plain was periodically covered by the channels of the branching and shifting streams. Its typical deposits should have been clean, fresh, well-assorted stratified sands and gravels. Any human relics left anywhere on the plain, even on portions not at the time occupied by the stream, should have been worked over and incorporated more or less deeply by scour-and-fill in the clean, stratified gravels and sands. None such are reported.

2. When the glacier had retired from the basin and no longer overloaded the Mississippi with its detritus, a transition stage should naturally have followed. During this the first work was to adjust the stream to the conditions that immediately followed the glacial retreat. It is to be presumed that the upper branches of the river were aggraded

to different slopes, dependent on their relations to the glacial supply of detritus thrown into them. As a rule, the gradient is much higher near the ice edge than at a distance from it. These high gradients are presumably the first to be reduced, while the material so derived is shifted to the lower gradients which continue their aggradation until the whole becomes adjusted to the new conditions. It must also be considered whether the fresh drift surfaces left by the recent retreat of the ice and the numerous new trenches of the young streams engaged in developing the new drainage system may not have kept the Mississippi in an aggrading, or at least static condition for a notable period after the direct influence of the ice sheet was withdrawn. Any human relics left on the plain during this stage should normally have been subject to incorporation by scour-and-fill in the clean, fresh, stratified gravel. But none are reported.

3. After the stage of transition had passed and the Mississippi had assumed the degradational phase, a period must probably be recognized during which its shifting meanders occupied the whole of its plain — except occasional protected embayments — and degraded it from side to side, removing the whole surface of the previous glacio-fluvial and transitional-adjustment plain. This action is dependent on the balance of prevailing conditions, and these vary for different rivers and different portions of the same river. To a large extent, the Mississippi has continued action of this phase down to the present time and has cut away the whole of the upper part of the glacio-fluvial plain. It is only here and there in favored localities that any remnants that can with probability be regarded as portions of the upper glacio-fluvial plain can now be recognized at any great distance from the ice edge. Just how long the river would continue to occupy by its shifting courses the whole upper plain at Little Falls cannot be determined by any evidence given in the paper, but the stage should be recognized in the interpretation of the history of the region, and particularly in the determination of the age of the surface deposits of the plain as it now exists. Any human relics left on the plain in this stage would be liable to be incorporated in the clean stratified gravel by scour-and-fill. But none are reported.

4. After the stages above noted had passed, the river developed a more restricted track and limited its erosion essentially to this, sinking its channel gradually into the broad plain and covering the remainder only in flood time. It would continue to flood the upper plain until the channel reached a depth greater than the height of the flood stages.

What this height is habitually in this part of the Mississippi is not known to the reviewer. The range between low and high water is given by Abbott as twenty feet at St. Paul, thirty-five feet at the mouth of the Missouri, and fifty feet at some points below. From the data given in the paper, it would appear that in the natural river, before influenced by damming, the low water was from twenty to twenty-five feet below the main plain. If, therefore, an average flood stage were applicable to this locality, the deepening of the channel since the river floods rose to the plain could be estimated at only a few feet, but the barrier formed by the slate renders an estimate of the time very uncertain. If the slate were once much higher than now, it should have kept the river longer within reach of the plain at flood time, so that the hypothesis that the slate has been notably cut down by the river, introduced to avoid the criticisms of Holmes and Hershey, is not without its embarrassments in another direction.

Now, it seems clear from the evidence presented in the paper that the quartz chips were not spread over the plain while the clean stratified gravels were being formed, nor while the river was meandering over the plain in its transitional-adjustment stage, nor in its general degradational stage, for at all of these stages, scour-and-fill should have incorporated the chips in the stratified sands and gravels. The chips were quite clearly introduced after the Mississippi had "withdrawn into the narrower limits of an eroded stream bed" and while only its flood stages overflowed the upper plain. This normally occurred in the fourth stage sketched above. As the recent cutting down of the channel has been slow on account of the slate barrier, a very considerable period has probably elapsed since the Mississippi last reached the upper plain even in its highest flood stages, except as these might be made exceptional by ice jams and similar obstructions. This gives the origin of the chips a respectable antiquity, but does not offer any presumption that it fell within the glacial period, or even very near its close. This seems to the reviewer to be the normal interpretation of the evidence presented in the paper.

T. C. C.

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A NATURAL GAS EXPLOSION NEAR WALDRON, IND.

Introduction.—On the eleventh day of August, 1890, a natural gas explosion of much violence occurred near Waldron, in Shelby county, Indiana. The ground was disturbed, and fractures, crevices, and craters were formed over an area of several acres.

Many newspaper accounts of the explosion were published. In most cases these were greatly exaggerated. Bare mention of the occurrence was made by E. T. J. Jordan, natural gas supervisor of Indiana, in his report to the state geologist, in 1891.[1]

In discussing a violent natural gas explosion that occurred at Coffeyville, Kan., on July 26, 1894, Haworth refers to a similar explosion that had occurred in Indiana, giving the locality as Kokomo; he says:

> One similar occurrence is known in the gas field of Indiana, near Kokomo, in which a fissure was formed in the solid limestone from which natural gas escaped with explosive violence and caught fire from a burning log heap near by.[2]

Haworth refers here to the Shelby county explosion, which did not occur near Kokomo, however, but took place about one hundred miles south and slightly east of that city. Neither was a visible crevice formed in solid limestone, as the explosion occurred in an area that was covered with soil and gravel, though

[1] *Indiana Department of Geology and Natural Resources, Seventeenth Annual Report*, p. 338. Indianapolis, 1892.

[2] *Kansas University Quarterly*, Vol. IV, p. 95. (Mr. Haworth's information concerning the Indiana explosion was obtained from Mr. William Moore, of Kokomo.)

limestone crops out near by (at *L. S.* Fig. 1) and also ¼ mile up stream from the area of the main explosion.

Later (1899), in a report upon the Waldron shale, made to the state geologist of Indiana, Mr. J. A. Price states briefly such facts concerning the Shelby county explosion as could be gleaned from statements of the citizens of the neighborhood at that time.

Except for the brief notices mentioned above no account of this interesting explosion has appeared in any scientific publication, so far as the writer is aware, and it is with a desire to place on record the salient facts concerning it that the following map, figures, and paper are published at this time.

The writer visited the locality on August 15, 1890, four days after the explosion occurred, while its effects were still fresh, and while the gas escaping from the crevices and craters still burned intermittently when ignited. From notes taken at the time, a map was prepared and a short account of the explosion was written, and read on November 7, 1890, before the Indiana University Scientific Society. The map and facts of the present paper are taken from the paper read, but not published at that time.

The figures are reproduced from photographs obtained from J. T. Schaub, Hope, Ind., and Everett Ayers, of Germantown, Ind.

Location.—The explosion occurred near the center of section 7, 11 north, 8 east; the affected area is two and a half miles south, slightly west of the village of Waldron, and two and a half miles west, slightly south of the village of St. Paul. Gas wells were reported to be producing at the time from both of these villages.

Owing to the fact that the Ogden Cemetery was at the edge of the disturbed area, the outburst of gas was known locally as the Ogden Cemetery "earthquake," "gas explosion," and "blow-out."

A total area of about ten acres was affected. The most violent explosion was limited, however, to a space of about two acres at the east side of the locality affected, and is shown approximately by the Nos. 1, 3, 5, and 6, Fig. 1. The topog-

raphy and relations of the area can be best understood by reference to Fig. 1.

The area that was shaken up lies at the south side of Big Flat Rock River or Creek, in an almost half circle bend formed by that stream, and is comparatively flat creek "bottom land"

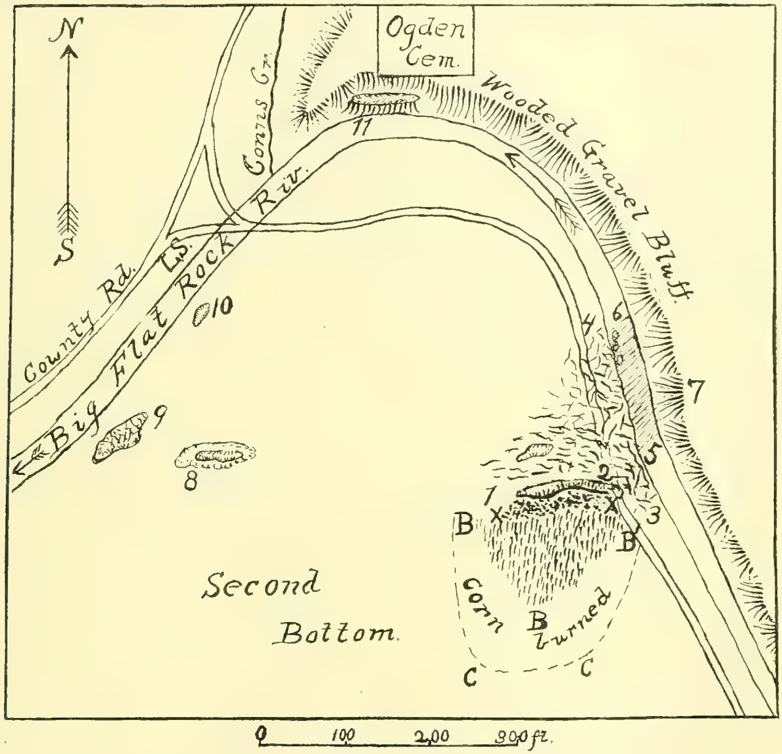


FIG. 1.—Map of the area affected by the Ogden Cemetery gas explosion, in Shelby county, Ind.

made up of alluvium. The south side of this area, marked "second bottom," (Fig. 1) is slightly higher than the portion, included by the Nos. 4, 3, 1, 8, 9, 10, and 11, in which the explosion occurred. At the time of the explosion growing corn covered the second bottom.

At the east and north side of the stream is a wooded bluff, of glacial gravel and clay, about forty feet high; this bluff was

covered with forest trees at the time of the explosion. There were also a few trees of considerable size bordering the creek on the side across from the bluff.

Geologic relations.—Most of the area affected by the explosion is covered by alluvial soil or gravel; only one exposure of rock in place occurs (viz., at *L. S.*, Fig. 1). Rock in place (belonging to the Niagara group) outcrops one-fourth mile up stream from the area of the main explosion, and in the affected area the limestone is probably only ten or twenty feet below the surface. The strata of this region lie approximately flat.

The rocks which underlie the region are shown by the following section of the strata passed through in drilling the gas well at C. J. Bickhart's mill, about two miles east of Ogden Cemetery.

SECTION AT BICKHART'S MILL.[1]

1.	Clay - - - - - - -	4 feet
2.	Limestone (Niagara, in part at least) - -	86
3.	Shale (Hudson River) - - - - -	774
4.	Limestone (Trenton) - - - - - -	22
	Total - - - - - -	886

Gas with a pressure of 335 lbs to the square inch was struck at nine feet in the Trenton limestone.

An irregularly bedded, porous conglomerate which gives off a fetid odor from a freshly broken surface is exposed for 150 feet along the east bank of the river about 150 yards above the area in which the main explosion occurred. This conglomerate is made up for the most part of coarse sand and small pebbles, but it contains some bowlders at least eight inches in diameter; it dips 30°, N.30°E., and is overlain by soft glacial clay and gravel. This is probably a locally hardened glacial deposit, and, if there is any connection between it and the gas explosion, that connection is not apparent to the writer.

Character and results of the explosion.—The explosion occurred about 9 o'clock, on the morning of August 11; it does not appear to have been accompanied by any violent report, for the attention of the people living in the neighborhood was first

[1] Reported by C. J. Bickhart in 1902.

FIG. 2.—View up the river from near the point 4 in Fig. 1. The county road which was made impassable by the explosion is seen at the right of the center of the picture. The trees that are barren of leaves had their leaves and smaller twigs burned off. The trees at the left of the picture are on the east side of the river and had their leaves browned by the heat. Most of the people in the background are standing on the earth blown out at the south side of the main fissure, x–x^1, Fig. 1. Blown down corn is barely shown at the right end of the picture. At the left end trees blown down by the explosion are shown, as is also the elevated bottom of the creek, where water stood prior to the explosion. From a photograph taken August 12, 1890.

attracted by a roaring or whizzing sound like the escape of steam from a boiler, but much louder. Upon looking toward the river, a sheet of flame was seen extending about 250 yards along the east side of the river bend. Regarding the height of the flame, estimates of those in sight at the time varied between 150 and 300 feet or more.

The height and intensity of the flame were sufficient to sear the leaves on the trees standing on the gravel bluff east of the river, and to completely burn off the leaves and small twigs from the trees standing near the fissures through which the gas escaped.

The vegetation around the openings (8, 9, 10, Fig. 1) at the west side of the area showed that the gas that escaped from those openings did not burn.

The roaring and flame continued at their height for about fifteen minutes, and then gradually subsided, and the gas burned from only a few of the crevices that had been formed.

The explosion had opened up a great number of crevices in the soil near the river bank (3–4, Fig. 1. See Fig. 2 also). When the ground was visited by the writer, these fissures varied in width from a few inches to four or five feet, with a like variation in depth, the shallowness being caused by the caving in of the soft soil at the sides and from the top.

Some of the fissures had evidently been formed by the upheaval, or depression, of the surface which had been elevated in some places, and in others had sunk down as much as four or five feet. The larger fissures, however, showed that they had been formed by the soil being blown out from below, the blown-out material being piled up at the sides of the fissures.

The character of the fissures is shown by Fig. 2, which shows also the "heaved up" condition of the surface. The center of the public road is shown in the foreground at the right side of Fig. 2. At this place (corresponding to the point 2 in Fig. 1) the road was so twisted and fissured as to be impassable.

The river bed from 5 to 6, Fig. 1, had been raised several feet, leaving the bottom exposed where water had stood before, while the west bank of the stream, from 3 to 4, Fig. I, had sunk

several feet. It was reported that the river flowed into the crevices between 3 and 6, Fig. 1, for some hours after the explosion.

Forest trees near 3, 5, and 11, Fig. 1, had been blown up by the roots and blown several (10–20) feet from where they had stood. The leaves on the trees and bushes from 5 to 11, Fig. 1 (about two hundred yards) were seared by the heat. On the west side of the creek from B' to 4 the smaller branches (and in some cases the bark) of the trees were entirely burned off.

FIG. 3.—View from the east side of the stream below 7, Fig. 1, looking westward across the river towards the point where the explosion was most violent. The trees shown in the water were blown up by the explosion, as were also the piles of earth along the river bank on which the figures stand.

Many of the trees were completely plastered from bottom to top with a fine mud, unlike anything exposed at the surface. This mud must have been thrown out with great force, as was shown by the manner in which it was plastered upon the trees and corn of the affected area. Lying about the fissures and over the surface were large quantities of this mud, which, upon drying, hardened somewhat and was easily cut into various designs, which were sold as souvenirs to visitors who came in great numbers to the locality.

Examined under the microscope, this mud is seen to be composed of an impalpable powder, such as might have been formed by direct precipitation of its constituents from solution.

ANALYSIS OF THE MUD BLOWN FROM THE CREVICES.

A. J. Cox, analyst.

	Per Cent
Lime (CaO)	13.4
Magnesia (MgO)	4.30
Iron oxide (Fe_2O_3)	15.45
Silica and insoluble silicates	49.75
Carbon dioxide (CO_2)	12.10
Water	5.6
Total	100.6

When seen by the writer, the principal fissure formed by the explosion (see 1, 2, Fig. 1) was between fifty and one hundred feet long, about five feet wide, and five feet deep. This crevice had evidently been much deeper, but when the gas ceased escaping under sufficient pressure to keep it open, loose earth had caved into it and partially filled it. The fissure extended almost east and west, and was along the foot of the slope, between the second bottom and the lower ground. At its south side was a mass of earth, x–x', from five to ten feet high, that had been blown from the fissure.

A field of corn was growing south of the main fissure at the time of the explosion. About an acre of this corn, *B*, *B'*, *C*, *C*, Fig. 1, was burned brown by the heat, while half of this burned portion, *B*, *B*, *B'*, Fig. 1, was blown flat upon the ground, and much of the blown down corn was plastered with mud. The corn was blown over toward the south, showing that the force came from the fissure at the north side. Some of the blown down corn is shown at the right end of Fig. 2.

At 11, Fig. 1, a slice of the gravel bluff was shaken down by the explosion, and some trees were blown up by the roots.

Irregular openings or craters were blown out at 8, 9, 10, Fig. 1, but the explosion was not so violent here as at the east side of the affected area.

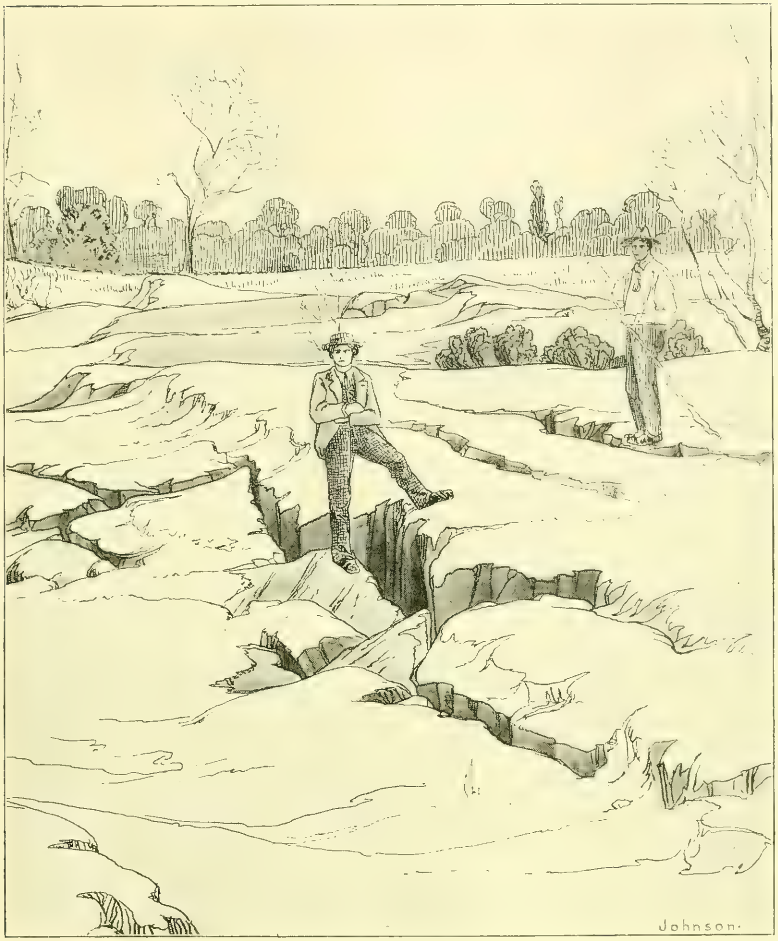


FIG. 4 —One of the fissures evidently formed by the earth cracking apart, owing to upheaval rather than by the earth being blown out. The piles of earth in the background of the picture correspond to x–x^1 of Fig. 1 and are at the south side of the main fissure, 1, 2 of Fig. 1.

When visited by the writer, four days after the explosion occurred, a little gas was escaping from many of the fissures, and this would burn for a short time when ignited.

It was reported by the citizens of the neighborhood that a fire had been burning in brushwood on a small island in the river about 150 yards above the main fissure previous to the explosion,

and it is probable that the escaping gas was ignited by this fire.

The accompanying figures show the nature of the fissures that were produced by the explosion.

Cause of the explosion.—The explosion was supposed at the time to have been caused by gas escaping below the casing from the wells at either St. Paul or Waldron, or at both places, and finding its way between the strata to the point where the explosion took place, at which point the strata were too weak to withstand the pressure.

Whether the gas did come from these wells, whether it came up from below through a crevice, or whether it was generated at no great depth in the strata, more or less directly below the area where the explosion occurred, is not known.

It is evident, however, that gas accumulated below an impervious layer until the pressure became sufficient to rend this impervious bed, when the explosion followed. The pressure required to do this cannot be known, because neither the depth nor strength of the confining strata is known.

It is obvious that gas, under a pressure of say two or three hundred pounds to the square inch, if confined by horizontal strata, sufficiently near the surface so that the weight of the overlying material would not equal the pressure of the gas, would tend to spread laterally between the strata, and to cause these to bend upwards. If the pressure should become great enough, the strata would finally break and the gas would escape, possibly with explosive violence. Such an explosion would not necessarily indicate that a large supply of gas was involved, for a small quantity would exert as great a pressure to the square foot as a larger one.

The area affected by the Ogden Cemetery explosion covered about ten acres; the pressure on this surface at 250 pounds[1] per square inch would have been 36,000 pounds to each square foot of surface.

Taking the weight of the shales and surface soil as 175

[1] The "rock pressure" of the gas in some portions of the Indiana field in 1890 was over 300 pounds to the square inch.

pounds to the cubic foot, this pressure would have equaled the weight of the overlying materials at a depth of 205 feet.

Assuming the pressure of the gas to have been 250 pounds to the square inch, then the strata which enclosed the gas prior to the explosion may have been anywhere between the surface and a depth of 205 feet.

FIG. 5.—View looking southwestward from the top of the bluff at 7, Fig. 1. Prior to the explosion the water of the stream flowed over the surface of the ground shown in the right foreground of the picture. (From a photograph.)

In closing, attention is directed to the fact that the locality in which the Ogden Cemetery explosion occurred is near the southwestern edge of the natural gas area of Indiana, and that

the Trenton limestone, the great gas producing formation, is about 850 feet below the surface at this point.[1]

J. F. Newsom.

Stanford University,
August 25, 1902.

[1] At Geneva, three and one-half miles southwest from Ogden Cemetery, Trenton rock (the gas producing bed of the region), was struck in a gas well at a depth of 832 feet. At Bickhart's mill, about two miles east of the cemetery, Trenton was struck at a depth of 864 feet, with gas at a pressure of 335 pounds to the square inch.

ETCHING OF QUARTZ IN THE INTERIOR OF CONGLOMERATES.[1]

General statement.—Those who have studied the Coal-measure and other highly siliceous conglomerates have frequently reported the occurrence of distinct evidences of etching of the quartz pebbles on certain of the exposed surfaces. The portion removed by the etching solutions may amount to as much as nine-tenths of the original pebbles, though one-third to one-half of their mass are more common amounts (Fig. 1). The pebbles affected exhibit strongly pitted and usually very rough surfaces on the exposed parts, while the portions remaining imbedded in the matrix retain unaltered their rounded water-worn characters. The position in which the etched pebbles have been most generally observed is upon the flat upper surfaces of ledges or upon similar surfaces of detached blocks, but instances have been noted, especially in the region about Olean, N. Y., where the etching is also strongly developed on the under sides of overhanging ledges. So far as known the only published discussion of the phenomena is by Dr. C. W. Hayes[2] who regards the etching as a superficial feature due to the action of azo-humic acid under ordinary atmospheric conditions.

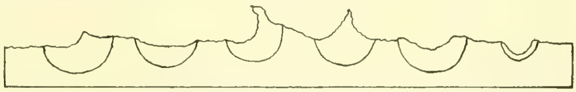


FIG. 1.—Section showing characteristic outlines of etched surfaces. Generalized from surface shown in Fig. 2, *A*.

Character of etching of conglomerate at Blossburg, Pa.—While examining the talus from an outcrop of Pottsville conglomerate at Blossburg, Tioga county, Pa., in 1901, the writer noted certain peculiarities which suggested that the quartz etching might be, in part at least, an internal rather than a superficial feature of the rock. The peculiarities first noted consisted of strongly

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] "Solution of Silica under Atmospheric Conditions," *Geol. Soc. Am., Bull.*, Vol. VIII, pp. 213–20.

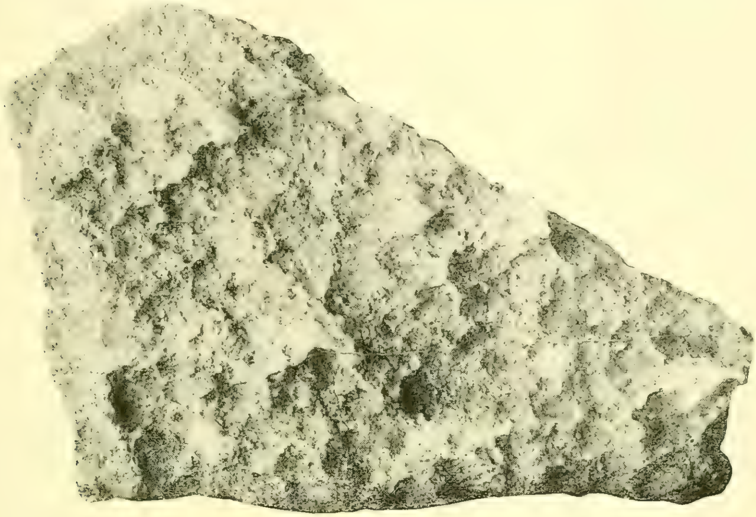
etched pebbles (Fig. 2, *A*) upon the flat surface of a fragment of conglomerate which, judging from its shape, was a part of a much larger bowlder which had split apart along the etched surface. This seemed to indicate an internal etching along a bedding plane, but could not be regarded as conclusive. Further search, however, brought to light bowlders several feet in diameter in which etched bedding planes could be traced through the mass of the rock. Because of the thickness of the bowlders, specimens of the etched surfaces were difficult to obtain, but the character of the etching in a sandy portion of the rock is shown in the illustrations *B* and *C* of Fig. 2, which are from photographs of specimens taken from opposite sides of an etched plane extending through a bowlder of some size. Not only are the surfaces strongly pitted by the complete removal of a portion of the grains, but under a glass the individual grains, even those of the smallest size, exhibit distinct evidences of etching, either by distinct pittings, or by the general "ground glass appearance" of their surfaces.

Still further examination brought to light evidences of etching within quarried blocks at distances of five feet or more from the surfaces, but in these cases the etching was confined to the immediate vicinity of plant remains, now carbonized or changed to coal, and, so far as could be detected, was not connected with either etched or unetched bedding or joint planes. The etching, though distinct, was not of the pronounced type characterizing many of the bedding planes (Fig. 2, *A*), but was more of the character shown by the illustrations *B* and *C* of the same plate.[1]

The etching, so far as noted at Blossburg, was confined to the bedding planes or to the vicinity of the vegetable remains in the

[1] Specimens of quartz pebbles from the Carboniferous conglomerate of Ohio showing strong impressions of plant stems, were exhibited at the Cleveland meeting of the American Association, in 1853, by Professor Jehu Brainerd. These impressions, as urged by Professor J. S. Newberry, were probably due to the action of humic acids evolved during the decay of the vegetable matter, and appear to be of the same nature as the etching about the plant remains in the conglomerate at Blossburg. (See JEHU BRAINERD, *Origin of the Quartz Pebbles of the Sandstone Conglomerate and the Formation of Stratified Sand Rocks*, Cleveland, 1854, p. 16; and J. S. NEWBERRY; *Ohio Geol. Surv.*, Vol. II, Pt. I, 1874, p. 111.

mass of the rock. The portions of the conglomerate bowlders lying in the humus or exposed to the atmosphere, though sometimes presenting roughened surfaces suggesting etching, proved



A.

B.

C.

FIG. 2.

A. Etched surface of a bedding plane in Pottsville conglomerate from Blossburg, Tioga county, Pa.

B and *C.* Etched surfaces from opposite sides of bedding plane in a sandy portion of Pottsville conglomerate from Blossburg, Tioga county, Pa.

on examination to be unetched, the roughening being due to the separation of entire grains by the ordinary processes of disintegration. The deep channels and pot-like cavities observed in

the conglomerate at other points in Pennsylvania and described by Mr. Arthur Winslow[1] are of similar origin, the only work of solution apparently being the removal of the cement binding the grains together. The disintegration of the conglomerate into sand likewise appears to be unaccompanied by solution, except that of the cement.

Where the etched surfaces are fully exposed to the action of the weather, as on the upper surfaces of ledges, they are, so far as known, always bleached to a gray or white color, but where they are more or less protected, as on the under sides of overhanging ledges, they are almost invariably stained with iron. It is a well-known fact that the action of the humic acids is accompanied by a leaching of the iron constituent, or at least a conversion of the iron to the ferrous state, in which it is ordinarily inconspicuous. The oxidized condition of the overhanging surface would seem, therefore, to indicate that the etching, if due to the action of the organic acids mentioned, is not going on at the present time. The portions of the bowlders in contact with the humus of the soil, though not etched, are distinctly bleached.

Summary of evidence.—The evidences that the etching probably took place in the instances described in the interior of the conglomerate at some past time rather than at the surface under present conditions are as follows:

1. Etching has been noted about vegetable remains at distances of several feet from the nearest exposed surface, showing that the solution is not a superficial feature.

2. Bedding planes extending throughout bowlders of several feet in diameter are frequently etched throughout, indicating the penetration of the solvent to distances of at least a number of feet from the surfaces.

3. The continuations of horizontal etched surfaces, both on the upper and overhanging portions of ledges, frequently extend up to and disappear into the mass of the rock, the exposed

[1] "Peculiarities of the Weathering in the Pottsville Conglomerate," *Science*, Vol. III, pp. 12–14.

parts, in fact, apparently being portions of much larger surfaces, reaching well into the interior of the rock mass.

4. The etched surfaces, except those about the vegetable remains, appear generally, if not always, to be confined to principal or to cross-bedding planes, or at least to joints, or other planes of separation, such as might have afforded a passage for solutions through the rock. The general absence of etching on surfaces other than the types mentioned, especially on the exposed exteriors of the masses, strongly suggests that the etching was internal.

5. The lack of bleaching on many of the etched surfaces shows that the etching is not the result of organic solvents acting at the present time, and affords negative evidence in favor of internal solution.

Conditions during the etching.—On examining the etched surfaces, it is found that only the immediate exterior is affected, the pebbles and sand grains being pitted or planed down to a general surface, without there being, in most cases, the slightest evidence of solution of the cementing materials (Fig. 3). This evidence tends to show that the rocks were consolidated when the etching took place, and probably indicates rapid action of the etching solutions, for if the rocks were open and porous, as they would have been before consolidation, or if the solutions passed through them for considerable lengths of time, it seems almost certain that the solutions would have penetrated for some distance into the body of the rocks and would have produced an internal etching or disintegration of the portions adjoining the bedding or other planes along which the solutions passed. The existence of small open cavities about the vegetable remains is also probably to be regarded as evidence of the consolidated condition of the rock at the time the solution took place.

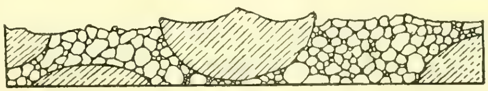


FIG. 3.—Diagrammatic section showing character of etched surfaces of conglomerate. (C. W. HAYES, *Geol. Soc. Am., Bull.*, Vol. VIII., p. 217.)

If the internal nature of the etching of the conglomerate is admitted, the question arises as to whether it occurred while the

latter was deeply buried or after it had become exposed at the surface through erosion. The extent of some of the etched surfaces, frequently amounting to several yards, or even rods, and the apparent continuation of these surfaces indefinitely into the rock, though affording no positive evidence, is at least suggestive of deep-seated conditions. The evidence afforded by the bowlders, however, appears to be more to the point, for it is difficult to conceive of conditions which would permit solutions to enter such bedding planes and to penetrate and etch the pebbles throughout their extent, while the external portions of the same bowlders, both where exposed to the atmosphere and to the humus of the soil, are entirely without evidences of etching.

Source and nature of the solvent.—The more sandy portions of the conglomerate at Blossburg contain considerable numbers of feldspathic grains, which, on weathering, it may be conceived, might have afforded alkaline solutions of sufficient strength to have produced an etching of the quartz. The fact, however, that other sandstones and conglomerates higher in feldspathic constituents in equally advanced stages of alteration, do not, in general, show any evidences of etching, makes it improbable, in the present instance, that the alkaline solutions were the active etching agents.

There appears to be no reasonable doubt that the solutions, which produced the etching about the fossil vegetable remains, were derived from the vegetable matter itself, in the process of the change from the original woody state to the present carbonized condition. Vegetable remains are abundant in many parts of the conglomerate, and must have furnished considerable quantities of organic acids. If, in fact, such was the source of the etching solutions, the latter, in order to reach the bedding planes or other passages, must have traversed the mass of the rock, probably through the agency of the force of capillarity. That the portions of the rock thus traversed are lacking in visible etching is probably due to the wide diffusion of the solutions and the relatively immense areas of the surfaces of the constituent grains.

The evidence, as far as it goes, would appear to favor the

view that the solvent had its origin in the vegetable matter of the rock itself, that it was concentrated along bedding planes or other passages in the rock, and that it was only where so concentrated that visible etching was produced. The etching is not, however, to be necessarily considered as confined to those parts of the rock abounding in vegetable remains, the solutions probably being conducted by the bedding or other planes to portions remote from the original source of the solvent.

Conclusions.—The observations have been insufficient to warrant broad generalizations, but the evidence, though not so decisive as might be desired, seems to favor, as far as the Blossburg locality is concerned, the conclusions given below. It is not probable, however, that they will hold for the occurrences at all localities.

1. The etching has not taken place under existing conditions. This is indicated by the unetched character of the portions of the rock exposed to the atmosphere or to the humus of the soil, and by the present oxidized condition of most the etched surfaces.

2. The etching is an internal feature, as is indicated by the etching about the plant remains, by the etched interiors of detached blocks, and by the extension of etched surfaces into the mass of the rock.

3. The etching took place after the rock was fully consolidated, as is shown by the fact that it is confined to the immediate walls of the bedding or other planes, the etching solutions failing to penetrate the rock or even to dissolve the cementing material except very locally.

4. The etching is believed to have taken place while the rock was moderately deeply buried, the depth, however, probably not exceeding 500 feet, this being a common limit of the circulation of fresh water below the general surface, as shown by the numerous oil and gas drillings in Pennsylvania.

5. The active solvent was probably an organic acid and was most likely derived from the vegetable remains within the rock itself.

Myron L. Fuller.

U. S. Geological Survey.

THE OIL- AND GAS-PRODUCING ROCKS OF OHIO.[1]

This state began producing oil in 1860. From that period until 1885 the output was restricted to the eastern part of the state, and was derived entirely from rocks of Carboniferous age. The production during that time was relatively small, and of little importance in a commercial sense. In 1885 the vast repository in the Trenton limestone was discovered, and this at once gave the industry in the state great impetus. The yield was such that in 1895 it surpassed that of Pennsylvania and New York combined, and since that date the state has held the first rank. Gas first became an important fuel in Ohio in 1884, the year of the great discovery at Findlay. From 1888 to 1900, inclusive, the value of this product exceeded $28,000,000.

The rocks, particularly the lower ones, producing these vast supplies have been in part studied, especially by Orton,[2] but thus far no paper has been published which considered all the producing strata. It is the purpose of this article to enumerate these, to discuss briefly their composition and general characters, and to show their stratigraphical position.

THE ORDOVICIAN.

In Ohio the upper half only of this great division needs be considered. This is divided by Orton as follows:

3. Hudson River series - - -	300–750 feet
2. Utica shales - - - -	0–300
1. Trenton limestone - - - -	50

The upper two members contain both oil and gas, but rarely in commercial quantities. Occasionally high-pressure gas wells are found, but these soon give out. Nowhere in Ohio can either of these formations be regarded as a producer of natural gas. Occasionally in the northwestern corner of the state oil is found

[1] Published by permission of Edward Orton, Jr., state geologist.

[2] *Geological Survey of Ohio*, Vol. VI, and *First Annual Report* (1890).

in the upper members, and wells are known that have had a large initial production ; but it is a general rule that such wells rapidly decrease, falling far short of their early promise.

THE PRINCIPAL DIVISIONS OF THE GEOLOGICAL SCALE IN OHIO, AND THE OIL- AND GAS-BEARING MEMBERS.

- Carboniferous
  - Coal measures
    - Goose Run sand
    - Mitchell sand
    - First Cow Run sand
    - Macksburg 500-foot sand
    - Second Cow Run sand
  - Lower Carboniferous
    - Logan group
      - Maxton sand
      - Mountain limestone
      - Big Injun series
        - Keener sand
        - Big Injun sand
        - Squaw sand
    - Berea grit
- Devonian - - - - - - - Ohio shales
- Silurian - - - - - - -
  - Lower Helderberg sand
  - Clinton sand
- Ordovician - - - - - - - Trenton limestone

The Trenton limestone.—Quite the reverse, however, with the first member, known as the "Trenton limestone." Not only is this the most important source of oil in Ohio, but probably it is not excelled by any single formation in the world. It forms the floor, so to speak, of the entire state, being found wherever the drill penetrates to a sufficient depth. It is disputed whether or not the formation reaches the surface anywhere, but Dr. Orton considered the exposure near Point Pleasant in Clermont county as forming the top of the Trenton.[1]

The composition of the Trenton has been made the subject of careful investigation by Orton, who found that the oil- and

[1] *Geological Survey of Ohio*, Vol. VII, p. 4.

gas-bearing beds are magnesian. This is shown by the following analyses:

	$CaCO_3$	$MgCO_3$	Ins. Res.	Al and FeOx.
Findlay gas rock..........	53.50	43.05	1.70	1.25
Bowling Green gas rock....	51.78	36.80	4.89	....
Lima oil rock.............	55.90	38.85	.75	2.94

It was further found that in some places at least the magnesian character of the rock changes rapidly from the surface of the formation down. Thus an analysis of the rock lying 100 feet below the top of the Trenton at Bowling Green showed over 88 per cent. of $CaCO_3$ and less than 7 per cent. of $MgCO_3$; while, as shown above, the upper portion of the same formation has less than 52 per cent. of $CaCO_3$ and more than 36 per cent. of $MgCO_3$. The magnesian character is important, since it renders the rock porous, thus making it a suitable reservoir for the oil and gas. Outside of the producing territory in Ohio the Trenton loses its magnesian character, the $CaCO_3$ composing usually at least 75 per cent. of the formation.[1]

The rock is often highly fossiliferous, and occasionally the pieces brought up by the sand pump are little more than a cemented mass of shells, resembling in this respect the limestones of the Hudson River series. Dr. Orton referred the formation, as shown in the Findlay well, to the Galena, Trenton proper, and Birdseye divisions.[2] The total thickness of the Trenton in northwestern Ohio is unknown, but it exceeds 780 feet. In the southwestern part of the state it is 650 feet, as shown in a well drilled on the McGhee farm in Liberty township, Adams county. This thickness is similar to that reported in Kentucky.

The relation stratigraphically of the Trenton to the next important producer, the Clinton, is shown in the following records:

[1] *Ibid.*, Vol. VI, pp. 103, 104. [2] *Ibid.*, Vol. VI, p. 116.

WELL NO. 1, HAINES FARM, ROSEVILLE, SANDUSKY COUNTY

Drive pipe		30 feet
Niagara series,	Gray lime	140
	White lime	160
	Blue lime	20
	White slate, first break	2
	Brown lime, hard	21
	Light slate, second break	20
Clinton limestone		100
Medina shales (red)		80
Hudson River series (white shales)		427
Utica shale (brown)		252½
Trenton limestone at		1,252½

For comparison a record is given of a well drilled on the Rohr farm near Groveport, Franklin county, in the central part of the state:

Drift	136 feet
Ohio shales	167
Cornifereus limestone, top at	303
Niagara limestone, bottom at	980
Clinton shales	110
Clinton sand, shells only at	1,110
Trenton limestone at	2,146
Bottom of well (in Trenton)	2,675

THE SILURIAN.

The rocks of this age in Ohio are divided by Orton as follows:[1]

4. Lower Helderberg limestone	50–600 feet
3. Niagara limestone and shale	125–380
2. Clinton group	20–150
1. Medina shale	25–150

The Clinton.—Of these divisions the second and fourth only call for recognition in this article. Along its line of outcrop in southwestern Ohio the Clinton consists essentially of a highly crystalline limestone, rich in fossils, especially crinoid stems. Commonly it has a light color, the tint of which varies from place to place. The rock takes a good polish, and is sometimes called marble. Occasionally the formation contains lean hematite, and

[1] *Ibid.*, Vol. VII, pp. 4, 5.

one of the earliest blast furnaces in the state relied on this ore. In composition the rock is calcareous, and at one point becomes the purest rock of this type in the state.

Northward, under cover, the rock undergoes notable changes, the result being that it closely resembles the overlying Niagara. It is in the central portion of the state, however, that the greatest change is found. Instead of a well-marked limestone, there is found in its place shales of different colors and composition and a conspicuous sandstone; the latter the repository for the great reservoirs of gas in Fairfield, Hocking, Licking and Knox counties. In northern Vinton county a pool of oil also has lately been found in it, and one well has been secured in Perry county.

The relations of these beds to the overlying Niagara are shown in the following partial log of a well on the Bauer farm near Sugar Grove. Samples of drillings below the Niagara were taken by the writer.

Berea grit		top at	620 feet
		bottom at	645
Corniferous, Helderberg, and Niagara limestones		top at	1,430
		bottom at	2,132
Clinton	Shales, light chocolate-colored. Little lime	top at	2,132
		bottom at	2,168
	Shales, green and chocolate-colored, the latter fossiliferous. Some lime	top at	2,168
		bottom at	2,199
	Shales, green and chocolate-colored. Much lime	top at	2,199
		bottom at	2,236
	Clinton sand at		2,236

Generally when the gas sand has been penetrated to a depth of from 10 to 15 feet the drill is stopped, and consequently data farther down are less abundant. In western Ohio the basal portion of the Niagara is commonly occupied by shales,[1] but northward and eastward this member contracts. In central Ohio it consists of shales and thin beds of limestone, and the bottom of these is regarded as the line of junction of the Niagara and the Clinton.

The following skeleton record of a well on the Spire farm near Sugar Grove shows the position of the Medina as well as the Clinton:

[1] *Ibid.*, pp. 11–13.

Drift	11 feet
Berea grit, bottom at	460
Corniferous, Helderberg, and Niagara limestones,	
top at	1,235
bottom at	1,921
Clinton sand, top at	2,025
bottom at	2,045
Medina (red shales) top at	2,055
Bottom of well at	2,075

This makes the red shales lying from 10 to 30 feet below the Clinton sand, the top of the Medina.

The Lower Helderberg.— Rocks of this age produce gas and oil in one locality, viz., near Jefferson, Ashtabula county. The succession of strata there is shown by the following record of Webb Well No. 1. All measurements were made with a steel line.

	Thickness of formation.	Total depth.
Drift	33 feet.	33 feet.
Ohio shales	1,671	1,704
Corniferous and Lower Helderberg limestones	288	1,992
Gas sand at		1,992

The sand, which is from 30 to 40 feet in thickness, is interbedded in the Lower Helderberg limestone. Similar conditions are found in Lucas and Wood counties, in the former of which the sand has been quarried for the manufacture of glass.[1] In the gas field under consideration the sand is moderately coarse, has a light color, and is highly fossiliferous. The gas is found in the top of the formation, and just below lies a large and threatening reservoir of salt water. A number of towns and villages are being supplied with fuel from this field. The oil wells are few in number and insignificant in production.

THE DEVONIAN.

The rocks of this age found in Ohio, have been classified by Orton [2] as follows:

3. Ohio shales	250–3,000 feet
2. Olentangy shale	25
3. Devonian limestone (Corniferous)	75

[1] *Ibid.*, p. 17. [2] *Ibid.*, pp. 4 and 18–26.

None of these formations produce oil, and the Ohio shales alone yield gas. The available supply of this, however is very small, and its use has been limited to domestic purposes. The principal counties have been those along the lake shore in the northeastern corner of the state. These shales, which underlie the eastern half of the state, are wedge-shaped, with the apex reaching from the lake to the Ohio. The cities, Columbus, Delaware, and Bucyrus, lie on or near this apex. Eastward the formation thickens rapidly and near Wellsville on the Ohio river has been penetrated to a depth of 2,600 feet without reaching the base. This feature has led to much confusion on the part of the driller, who has expected to find the interval between the Berea grit and the Devonian limestone, the same in the eastern part of the state that he did in the central.

The gas secured in these shales is not from any one horizon, but varies stratigraphically from place to place. The wells are all small. Very commonly the shales make a show of gas, but usually the yield is so light as to be commercially valueless. The aggregate amount contained, however, must be very large, and if it could be collected would form one of the most valuable supplies of fuel in the state.[1]

THE CARBONIFEROUS.

Classifying the formations of this great division, as has been customary, into the Lower Carboniferous, Coal-measures, and Permian, it is found that the oil- and gas-bearing rocks are restricted to the first two members. These will now be considered in order.

I. THE LOWER CARBONIFEROUS.

The Berea grit.—This is the most extensive sandstone of the state. Its area above and below drainage is about 15,000 square miles, or more than one-third of the area of the state. Its value is commensurate with its extent. "Its economic value above ground is great, but it is greater below. In its outcrop it is a source of the finest building-stone and the best grindstone grit

[1] For a full discussion of this subject see *Geological Survey of Ohio*, Vol. VI. pp. 410–42.

of the country, and when it dips beneath the surface it becomes the repository of invaluable supplies of petroleum, gas, and salt water."[1]

The composition and structure are very constant. The color is gray below drainage, but has a tinge of yellow above. The sand is of moderate fineness, and composed almost wholly of silica. Occasionally it contains carbonate of lime, probably as a cement, but this never constitutes more than a very small fraction of the formation. That found below the surface around the village Berea in Cuyahoga county is undistinguishable from that obtained at a depth of more than 2,000 feet in Washington county. Sometimes, though not usually, the formation divides, a bed of shale lying between two of sandstone; at other places the upper portion of the formation consists of sandstone and the lower of shales. In thickness the formation varies from 50 feet or more in the northern part of the state to a half dozen or less in the southeastern portion, and occasionally disappears entirely, its place being occupied by shales. The Berea grit is succeeded above by the Berea (Sunbury) and Cuyahoga shales, having usually an aggregate thickness of from 500 to 600 feet, and below by the Ohio shales, having a great and rapidly increasing thickness eastward. The most remarkable character of the formation, however, remains to be mentioned, viz., its persistence. From its outcrop it has been followed by the drill from county to county, and often from section to section, until the eastern and southeastern limit of the state is reached. It is as easily recognized below drainage as above, and this character makes it a stratigraphical landmark of great value to both driller and geologist. In many counties in the eastern part of the state, especially those fronting on the river, numerous efforts have been made to find a productive sand below the Berea, but in every case this effort has been unsuccessful. It may now be taken as having been demonstrated by the drill that when the Berea sand has been passed in this territory the last hope of oil or gas has gone.

While a trace of oil or gas has perhaps been found in every

[1] *Ibid.*, Vol. VII, p. 28.

county where the formation exists, the production in commercial quantities is limited to Lorain, Medina, Trumbull, Columbiana, Stark, Jefferson, Harrison, Belmont, Guernsey, Monroe, Noble, Vinton, Perry, Athens, Morgan, and Washington counties.

The Logan group.—The relative position of this group and the Berea is shown by the following skeleton record of a well on the Mead farm in the Elk Run Pool, Washington county.

Logan group	Salt sand	top at	1,200 feet.
		bottom at	1,280
	Maxton sand	top at	1,450
		bottom at	1,500
	Mountain limestone ("Big lime")	top at	1,510
		bottom at	1,545
	Big Injun series	top at	1,560
		bottom at	1,730
Berea grit		top at	2,124
		bottom at	2,138

This shows that the two formations are about 400 feet apart, and as has already been stated the interval is occupied by the Berea and Cuyahoga shales.

The Logan group, as classified by Orton, consists of three members — a conglomerate, sandstone, and shale — and has a maximum thickness of 350 feet.[1] Quite recently, however, Professor Prosser has considered the question, and he divides the group as follows:[2]

2. Logan formation = Logan sandstone and shales.
1. Black Hand Formation = Logan conglomerate.

Recent work by the drill demonstrates that the maximum thickness is twice that stated by Orton. The group is limited above by the Lower Carboniferous limestone, but this is rarely recognized in deep wells, and consequently the upper limit is usually uncertain. The first member of the group that is recognized by the driller is the Salt sand. The relation stratigraphically of this member to the Lower Carboniferous limestone is shown by the following record of a well on the Longshore farm in section 15 of Brush Creek township, Muskingum county. All measurements were made with a steel line.

[1] *Ibid.*, Vol. VII, pp. 4, 5, 32–5.

[2] JOUR. GEOL., Vol. IX, pp. 205–31.

Putnam Hill limestone -	top at	20 feet.
	bottom at	23
Lower Carboniferous limestone	top at	225
	bottom at	265
Salt sand - - -	top at	450
	bottom at	485
Berea shale - - -	top at	919
	bottom at	952
Berea grit - - -	top at	950
	bottom at	980
Bedford shales (brick red) -	top at	980
	bottom at	1,010
Ohio shales, top at - - - - -		1,010

This shows that the Salt sand lies 185 feet below the Lower Carboniferous limestone. Combining this with the record of the Mead well previously given makes a total thickness for the Logan group of 715 feet. Probably in the extreme southeastern corner of the state the thickness is still greater.

Above drainage the group is well marked. Hills capped with sandstone or conglomerate stand out in bold relief, so that the limits of the formation are discernible from a distance. The conglomerate is the most conspicuous member of the group. It is essentially a quartz rock, the largest pebbles of which do not commonly exceed one-half of an inch in diameter. It is the best known bridge stone in the state. The sandstone member has usually a yellow or brown color, but sometimes this becomes strikingly variegated. It is extensively used for building purposes. The members of this group are much less constant in their physical characters than the Berea grit, and hence their identification is correspondingly more difficult.

Under cover the Logan group undergoes important changes, and the several formations are given different names from those at the surface. Thus, instead of the Logan conglomerate, sandstone, and shale, we have the Big Injun sand, Mountain limestone, Salt sand, etc. The correlation of the strata bearing these two sets of names is as follows. This is based on their stratigraphical succession and lithology. While the limits underground cannot be sharply drawn in most cases, they are perhaps as definite as those along the line of outcrop.

Logan shales	=shales (unnamed)
Logan sandstone	=Salt sand
Logan conglomerate	=Mountain limestone Big Injun series

The limestone just named, and which is known also as the "Big lime," has a maximum thickness in this state of 110 feet. It is a light-colored, hard, massive rock, free from oil and gas except along its margin, where the formation becomes broken and the layers of limestone are intercalated with sandstone. The formation is wedge-shaped with the apex to the northwest. It is limited to the eastern half of Washington and Monroe counties, and the southeastern corner of Belmont. To the west and north its place is occupied by shales and sandstones. The formation divides the Logan group into two unequal parts, and serves as a guide-post to the driller.

The Big Injun series.— This consists of the following members:

Slate - -	0– 20 feet
Keener sand - -	0– 60
Slate - -	0– 25
Big Injun sand	0–175
Slate - -	0– 10
Squaw sand -	0– 30

From this it is seen that the group varies greatly. Sometimes it is little more than one great mass of sandstone, while at other times it is broken into a series of alternating beds of slate and sandstone. The Keener sand occasionally lies immediately below the Mountain limestone, but more often is separated from that rock by a few feet of shales. It varies considerably in texture, but is usually coarse and open, sometimes conglomeritic. The sand was named from the Keener farm near Sistersville, West Virginia.[1] It is an important source of oil in Monroe and Washington counties. The sand is separated from the underlying Big Injun by a bed of slate. Sometimes the latter is wanting, and then the two sands run together and are conjointly called the Big Injun. The sand in question (Big Injun) is by far the thickest member of the series, but in other respects

[1] *West Virginia Geological Survey*, Vol. I, p. 357.

resembles the Keener. It is recognized in several counties in southeastern Ohio, but is a producer of oil or gas in commercial quantities in Monroe and Washington counties only. To the west and north the formation becomes too broken to be a repository for oil or gas. Below the Big Injun, and separated from it by a thin bed of shales, there is occasionally found another layer of sand known as the Squaw. It is decidedly patchy and never extends over large areas in this state. The best records of it are reported from Monroe county, but it is of little importance even there.

The Salt sand.—This is the highest of the sands of the Logan group. It has a gray color, is moderately coarse, and nearly always is charged with brine. Occasionally it contains a little oil and gas, but it cannot be recognized as a producer of either.

II. THE COAL-MEASURES.

While a large number of strata belonging to the Coal-measures have been or are now sources of oil, comparatively few of these have been important in a commercial sense. Generally the sands are local, and cannot be traced over an area of more than a fraction of a mile. Such sands usually have names, but because of their small area and production they will not be further noticed in this article. The most important sands of the Coal-measures are the following:

5. Goose Run sand.
4. Mitchell sand.
3. First Cow Run sand.
2. Macksburg 500-foot sand.
1. Second Cow Run sand.

The relative positions of sands 1 and 3 are shown by the following data taken from Centennial Well No. 6 at Cow Run:

	Thickness	Depth to top of formation
Pittsburg coal	1 foot	11 feet
First Cow Run sand	47 feet	325
Second Cow Run sand	64	776

The stratigraphical relation of sands 2 and 3 is shown by the following record taken from Dunn Well No. 6, near Macksburg. The well head is six feet below the Meigs Creek coal.

	Thickness.	Depth to top of formation.
Ames limestone, - - -	1 foot	285 feet
First Cow Run sand - - -	5 feet	385
Cambridge limestone -	4	411
Dunkard sand (300-foot) - - -	95	530
Macksburg 500-foot sand -	22	702

The Dunkard or 300-foot sand is quite generally regarded as the equivalent of the Mahoning. That this cannot be correct is shown by the following partial section of the Hocking Valley coal field.[1]

	Thickness.
Cambridge limestone - - - - -	2–10 feet
Mahoning sandstone, upper division, -	50
Brush Creek coal (No. 7a) - - -	2½
Brush Creek limestone - - -	4
Mahoning sandstone, lower division -	15–25
Upper Freeport coal - - - - -	0– 3
Upper Freeport { Clay, Shales - - -, Limestone and sandstone }	35
Middle Kittaning coal (No. 6) - -	5–13

This shows the Mahoning sandstone lying immediately below the Cambridge lime, but experience in the field demonstrates that the two are not ordinarily in contact. Measuring from the base of the lime rock to that of the Mahoning, an interval of 76 feet is found, while, according to the records in the Dunn well, the interval is 210 feet. A divergence of this sort cannot be explained by assuming that the section expands eastward, for a study of the relative positions of the Pittsburgh coal, the Ames and Cambridge limestones farther west with the same formations near Macksburg, shows no material change, and it is certainly unreasonable to assume that the formations just below the Cambridge limestone expand at anything like the rate that would be necessary to make the interval which this nomenclature requires. Further, naming the sand in question the Mahoning makes impossible a rational classification of the lower formations. The position of the sand with reference to the Cambridge lime is that of the Upper Freeport.

[1] *Geological Survey of Ohio*, Vol. V, p. 918.

The positions of sands 3 and 4 are shown by the record of Centennial Well No. 7, at Cow Run. The well head is at the horizon of the Meigs Creek coal.

	Thickness.	Depth to top of formation.
Pittsburg coal (No. 8) - -	1	116 feet
Mitchell sand - - -	25	205
Red shales ("Big Red") - -	80	235
First Cow Run sand - -	32	423

The relative positions of sands 4 and 5 are shown by the following taken from Reed Well No. 4, near Marietta:

Goose Run sand -	top at	300 feet
	bottom at	331
Mitchell sand - -	top at	525
	bottom at	546

The Second Cow Run sand.—This is one of the least important members of the group now under consideration. It has been a small producer at Cow Run in Washington county for more than thirty years, but rarely has been found beyond that locality. It is reported, however, quite frequently, for the driller gives this name to almost any sand lying from 100 to 500 feet below the first Cow Run sand. As may be seen from the records given the interval between the two is 400 feet. It lies 760 feet below the Pittsburg coal, and is the thickest member of the group, sometimes exceeding 60 feet. Occasionally the formation is divided by few feet of slate, in which case the oil lies in the lower part. The sand possesses no qualities that serve to distinguish it from the higher members.

The sand belongs near the base of the Coal-measures. The partial record of the Rice well, given below, shows it to be the first sand above the Salt sand, the two being separated by 79 feet of shales, the latter probably the equivalent of the shales of the Logan group. This, with the thickness of the formation, and the fact that it is sometimes divided by a few feet of shales, makes quite certain its identification as the Massillon sandstone.

The Macksburg 500-foot sand.—This is important at Macksburg and vicinity only. It lies 670 feet below the Meigs Creek coal

and about 580 feet below the Pittsburg, as is shown in the following partial log of George Rice Well No. 18, at Macksburg.[1]

	Thickness.	To top of formation.
Meigs Creek coal	5 feet	10 feet
First Cow Run sand	35	343
Dunkard sand (300-foot)	78	554
500-foot sand	17	685
Sand, pebbly (800-foot)	51	775
Slate	79	826
Salt sand	190	905

This sand commonly ranges from 10 to 30 feet in thickness. It is usually quite coarse, but does not become a conglomerate. Like the First Cow Run sand, it does not form a continuous stratum, but is decidedly patchy. Stratigraphically considered, the formation belongs near the top of the Conglomerate Coal-measures, and its position with reference to the Cambridge lime and Dunkard sand strongly indicates that it is the Tionesta sandstone.

The Second Cow Run and the Macksburg 500-foot sand have been regarded by many as equivalent. As has already been suggested by Professor White, however, this cannot be the case.[2] Examination of the record of the Rice well shows that the interval between the First Cow Run and 500-foot sands is only 307 feet, while, as already stated, the interval should be 400 feet. Measuring from the Meigs Creek coal, equally conclusive figures are secured. Thus the Second Cow Run sand lies 840 feet below the Meigs Creek coal, while the interval between this seam and the 500-foot sand is only 670 feet. The sand at Macksburg known as the 800-foot is probably the equivalent of the Second Cow Run.

The First Cow Run sand.—This is the most important and best-known sand of the group. As is shown in the record of the Dunn well, its position is 100 feet below the Ames limestone. In western Morgan county, near the outcrop of the sand, the interval ranges from 70 feet to 100. The Ames limestone there lies 170 feet below the Pittsburg coal. The identification of the

[1] *West Virginia Geol. Sur.*, Vol. I, p. 298.

[2] *West Virginia Geological Survey*, Vol. I, p. 299.

sand is made more certain by the fact that the Cambridge limestone lies immediately below or is separated from the sand by a thin bed of shales. Unfortunately these limestones are not recognized in Monroe and the eastern part of Washington counties, and hence the sand in question often cannot be identified there with certainty. In such localities any shallow sand, especially if it makes a show of oil or gas, is known as the Cow Run. The relation of the sand to the two limestones places it about 100 feet above the base of the Conemaugh formation.

If the Berea grit be taken as the type of a persistent stratum of sandstone, the First Cow Run sand may properly be selected as the representative of the opposite type. It is the most patchy of the oil or gas rocks of Ohio. The maximum thickness of the formation may be taken at 50 feet, but even a short distance from this the stratum may become very thin or actually disappear entirely. The texture varies much, and where productive is sometimes conglomeritic. Pebbles three-fourths of an inch in diameter have been found, and those one-fourth of an inch are common. The pebbles consist of quartz, but small grains of other minerals are found. From this type the formation changes to a hard compact sandstone.

The sand is an important source of oil in Morgan and Washington counties. It seems to have been first struck at Macksburg in 1860, where it is known as the 140-foot sand; this being the depth at which the sand was found in the valley at that place. In 1861 the sand was found at Cow Run and has there been a producer ever since. It is seen that the latter name has not the claim of priority, but it is so much more widely used that it is here retained.

The Mitchell sand.—This is the source of a small oil field a few miles east of Marietta. The sand is comparable in thickness with the First Cow Run, but in texture is less conglomeritic. As has been shown, it lies about 90 feet below the Pittsburg coal, or 200 feet above the First Cow Run sand. Its place is near the summit of the Conemaugh formation. Wells in this sand commonly begin with a relatively large production, but decrease very rapidly.

The Goose Run sand.—The formation known by this name has supplied a score or more small wells near Marietta. The sand is patchy, and the life of the wells very short. In fact, the rock is of little value, and is recognized here simply to make the record complete stratigraphically. Lying nearly 200 feet above the Mitchell, the sand belongs 100 feet above the Pittsburg coal, or, in other words, near the middle of the Monongahela formation.

The following table shows the great divisions of the Coal-measures of Ohio, and also the approximate positions, at least, in these of the several sands just discussed:

Dunkard formation, or Upper Barren Coal-measures, 500 feet.	No oil or gas rocks.
Monongahela Formation, or Upper Productive Coal-measures, 200 feet.	Goose Run Sand. 100 feet. Pittsburg or No. 8 coal.
Conemaugh formation, or Lower Barren Coal-measures, 500 feet.	90 feet. Mitchell sand. 200 feet. First Cow Run sand. Cambridge limestone. Mahoning sandstone.
Allegheny Formation, or Lower Productive Coal-measures, 250 feet.	Upper Freeport or No. 7 coal. Dunkard or 300-foot sand = ? Freeport sandstone. 50 feet.
Conglomerate Coal-measures, 250 feet.	Macksburg 500-foot sand = ? Tionesta sandstone. 70 feet. Second Cow Run sand = Massillon sandstone. Sharon or No. 1 Coal.

J. A. Bownocker.

Columbus,
October 10, 1902.

THE ARAPAHOE GLACIER IN 1902.[1]

In the front range of the Rocky Mountains of Colorado are several remnants of glaciers. One of these, the Arapahoe glacier,[2] has an area at present of about one-half square mile. It lies on the eastern slope of the continental divide, twenty-one miles due west from the city of Boulder. It is inclosed by nearly vertical walls five to seven hundred feet in height, forming a deep cirque opening to the east. The valley leading eastward is that of a branch of North Boulder Creek. This valley has been occupied by a glacier to a distance of at least eight miles to the east. The bottom of the valley for four miles eastward from the present glacier is occupied by a series of lakes resulting from the glacial action and the intervening topography is marked by roche moutonees (Fig. 1). The front of the glacier has retreated up this valley to its present position, and its length has been thereby reduced from nine miles to one mile.

The features of this glacier at the close of the summer of 1902 have a peculiar interest. The snowfall for the past three winters has been deficient, and the melting in the ensuing summers has been excessive. The results of these climatic circumstances appear in a great contraction of the ice-covered area, an unusual exposure of fresh moraines and, what is still more important, an almost complete absence of snow below the névé. This last condition is responsible for many fine exposures revealing the stratification of the ice, and for the complete uncovering of crevasses, some of which stand open as much as ten feet.

Moraines.—The bottom of the valley is far from being a single trough, and the glacier is therefore by no means a single

[1] The observations on which this account is based were made in the last week of August. The photographs were taken by Judge Junius Henderson, of Boulder, Colo. The map is constructed from a survey made by Hugh F. Watts, of Boulder, Colo.

[2] For a general description of this glacier, its position, dimensions, shape, and evidences of its true glacial character, see paper by WILLIS T. LEE, this JOURNAL, Vol. VIII, p. 647.

ice stream. In its more vigorous days, when it filled the valley for some miles and was some hundreds of feet deeper than at present, the inequalities of its bed must have been unable to control the ice movement to any great extent, and therefore failed to subdivide the glacier into a system of branching tribu-

FIG. 1.—Looking east, down the valley, from a point one-half mile below the present terminus of the glacier. The shelf seen at the left is in the main rock terrace. The lower and narrower valley suggests uplift and considerable erosion before the glacier was developed.

taries. It must then have appeared essentially as a single ice stream. Indeed, its appearance, as viewed from the neighboring mountains two years ago,[1] seems to have suggested but two branches, separated by a moraine so low that a few extra yards of depth would have rendered the whole a unit at the surface. The valley bottom below the present terminus is barred with crescent-shaped terminal moraines which mark the termini of

[1] WILLIS T. LEE, *loc. cit.*

the small glaciers into which the larger ice mass became divided in its dying stages. Other crescentic moraines are now just becoming exposed at the present border of the ice, the horns of the crescents being in the positions of medial moraines which were formed on the valley bottom between tributary glaciers, and are now for the first time being exposed by the wasting of

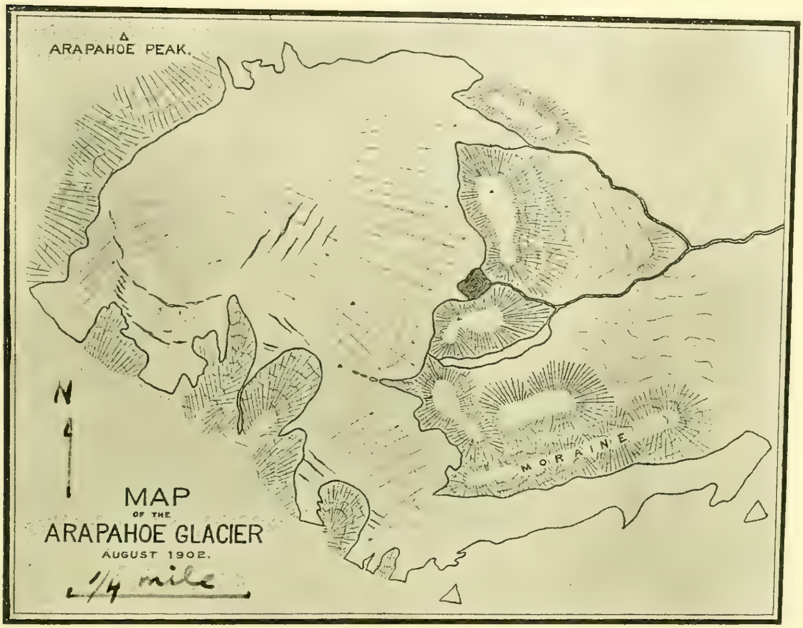


FIG. 2.

the ice. Several of these medial lines are distinctly terminal in their relations to the ice on either side, as shown by the fact that the movements of the ice are not in the direction of such lines, but normal to their trend from both sides. (One such is well shown on the map, Fig. 2.)

The moraines whose positions indicate that they have been for a long time exposed are composed, not of rounded bowlders, but of large fragments from among which all smaller stones have been removed. This statement is made of those near the present limit of the ice, and therefore formed since the

glacier became very short. Those situated some miles down the valley contain many rounded bowlders, for the obvious reason that many of these have traveled far. Between the moraines of great angular fragments and the ice, are newer ridges whose constitution is in striking contrast with that of the outer ridges. These newer deposits contain fragments of the same order of size as those contained in the older ridges, but intermixed with them are stones of all smaller sizes. In these ridges, often capping the several fragments or lying in masses at the very summit, are quantities of mingled mud and gravel so fresh that they bear almost no evidence of having been washed by the rains of a single season. They resemble nothing so much as the fresh dump from a great steam shovel. On the north side of the glacier such a ridge rises from forty to fifty feet above the present level of the ice, showing that the surface of the glacier has wasted by at least that amount since the ridge was formed. The unwashed character of its summit makes it difficult to admit that more than a single season has passed since its first exposure to subaërial weathering. This necessitates the conclusion that the glacier has wasted at least forty or fifty feet during the past summer.

The recent contraction of the glacier is further evidenced by the exposure of ice in one of the fresh morainic ridges now well separated from the body of the glacier (Fig. 3). Superficially this ridge differs not at all from any other moraine of recent formation. Except for the fortunate section which reveals its core, it would appear to be built of a framework of huge fragments, from among which the finer materials have been but partly removed by surface erosion. The section, apparently due to stream erosion, exposes a surface of perhaps twenty or thirty square yards of ice. The position of the stratification planes, dipping toward the head of the glacier, agrees with the supposition that these ice masses may still be in place, having been covered and protected by the abundant débris at the ice front. A second ridge of similar character, only partly separated from the glacier and several hundred feet within the first ridge, is plainly the result of the present summer's melting. The front of the ice was early in the season completely covered with

rock débris. This covering formed such a protection that the outer rim of the glacier wasted more slowly than the ice immediately in the rear. A trough has therefore begun, which in another season like the one just past, may grow to such an extent as to leave the inner ridge completely detached from the glacier.

FIG. 3.—Terminal moraine; the dark bands are ice. The rocks between the dark bands probably overlie ice. The stratification of the ice is transverse to the bands seen here.

The third steep ice front behind the second trough is already becoming covered with débris. A series of years of deficient snowfall or excessive melting, or both, might in this way produce a series of concentric ridges having ice cores, whose subsequent melting would leave a topography very much more choppy than that which would result from a series of ordinary recessional moraines. It is suggested that a part of the very confused morainic area several miles east of Silver Lake may thus be connected with the wasting of the glacier at an excessive rate.

Crevasses.—A second great advantage from the recent deficiency of snowfall and the excess of melting was found in the complete uncovering of crevasses. No part of the glacieris free

FIG. 4.—Crevasse, open about 10 feet.

from cracks, but near the middle a greater steepness of the bed gives rise to crevassing on a large scale (Figs. 4 and 5). The slope of the ice surface for some distance at this place was

measured at twenty-four degrees, which is greater than the slope at any other place excluding the névé and the immediate margin of the glacier. Many of the crevasses in this zone are forty rods long, and some stand open as much as ten feet. They are spaced at intervals of a few yards. The blocks thus formed appear to have been tilted forward. This is inferred from the fact that the

FIG. 5.—General view looking south over crevasses to the névé.

brink on the lee side of each crevasse is higher than that on the opposite or stoss side, and the surface of each block has a steeper slope than that of the ice as a whole in this vicinity. Lines dropped into these crevasses did not reach depths greater than fifty feet, but apparently water is running at much greater depths. The appearance of the ice in these crevasses is clear and bluish, with occasional bands which are stained as if with dust. In the same zone are some small cracks, limited in length to seven or eight feet, which stand open about two inches at the center.

Near the margin of the ice a system of longitudinal crevasses is made quite prominent by the control which these exercise over

the surface drainage. They reach apparently no great depths. Many of them, which are several feet in depth and contain running water, are open less than half an inch at the top. Much of

FIG. 6.—The Bergschrund, open about 15 feet. The columns at the right are ice; above them is snow.

the surface drainage follows these narrow crevasses. That they are primarily due to fracture and not to erosion is evident from their absolute straightness for long distances.

A most striking feature of this glacier is the prominent *Berg-*

schrund, or gaping crevasse, at the line which may be taken as the limit of the névé and the beginning of the glacier proper (Fig. 6). The very steep slope of the névé, its whiteness, and the solitariness of this great crack make it strikingly prominent from any point from which the glacier is visible. It is almost continuous around the cirque and stands open at many places as much as ten or fifteen feet. A partial descent into this opening revealed the fact that it traverses from ten to twenty feet of snow at the surface, below which is a colonnade of great icicles lining a chasm at least fifty feet deep. Independent of these icicles the walls of the chasm below the ten or twenty feet of snow, seem to be of the same blue ice which is seen in the crevasses at the center of the glacier.

In the examination of crevasses the excessive melting of the past summer proved a most fortunate circumstance. Probably every crevasse down to the most minute was uncovered. The real significance of this appeared after a snowfall of not more than two inches on August 28. On the following day many crevasses, having widths approximating ten inches, were found completely covered by crusts of snow. It seemed evident from this that a snowfall of a very few inches would easily obscure crevasses in which a man might be lost.

The complete absence of surface snow was of great advantage in observing the stratification of the ice. Dark lines which were nearly horizontal and continuous for long distances were plainly visible for some miles. These mark the outcrops of ice strata. The alternate strata are of clear ice, while the intervening ones have a more spongy texture, the constituent beds being for the most part not thicker than two inches and usually less than one inch. The wasting of layers of varying hardness produces small cliffs and platforms analogus to those observed in canyons cut in stratified rock. The fine débris accumulates along the lines of these outcrops and forms the dark lines which are visible for great distances. The dip of stratification planes near the margin of the ice is well seen in the canyons of surface streams and is uniformly toward the direction from which the ice comes (Fig. 7). Dips of thirty degrees or more

are common a hundred yards from the edge and the steepness increases as the margin is approached. Englacial drift disposed in planes was found at only one point and that was in the buried ice. The material incorporated here contained nothing coarser than sand. Planes showing discoloration, as if by dust accumulated on the surface, are not uncommon. In the larger crevasses

FIG. 7.—Stream channel showing stratification of the ice—100 yards from front.

these are sometimes very prominent in contrast with the clear bluish ice.

The drainage of the glacier has no special peculiarity, and in this lies its chief interest, because it aids in classifying this ice field with well-developed alpine glaciers. Streams are guided largely by crevasses and frequently drop suddenly into the body of the glacier. Pits are not uncommon; one of these, whose opening at the surface was less than ten square inches, was found to be three feet deep.

Where the ice is snow-covered and on the smaller segments which do not take on the nature of perfect glacier ice, there often results from the surface drainage a peculiar hummocky surface. The process by which these hummocks or knobs come into existence is somewhat indirect. The water draining from a very steep surface of uncompacted névé, produces at first a

FIG. 8.—Lake within the present terminal moraine. The prominent lines in the ice at the left are shearing planes.

system of small parallel channels, which may be a yard or two apart. The water in these channels percolates to some extent, and in freezing produces under the channel a rib which is harder and more ice-like than the snow between channels. Differential melting next leaves what was once a channel exposed as a ridge. This ridge has at no time an even crest, and soon comes to appear as a line of small icy hummocks regularly spaced at intervals of a few feet. The isolated patches of névé attending the Arapahoe glacier, which are just too small to take on com-

plete glacial character, often show this knobby surface to a remarkable degree.

The water issuing from below the glacier is characteristically milky. Small pools are found whose bottoms cannot be seen at depths greater than four inches. The turbid water escaping from below is soon mixed with the clear drainage from the surface, and the turbidity is thereby reduced; but the first few lakes of the long chain in the valley below are notably turbid.

There are no records of the extent of this glacier in former years. It is viewed from the rim of the cirque by occasional visitors to Arapahoe peak, but visits to the glacier itself have been rare. A few photographs taken from the surrounding heights in former years would indicate that the loss of forty or fifty feet in depth during the season just passed is not all to be credited to the permanent wasting of the glacier. That amount has plainly disappeared from the surface since last winter; this conclusion seems necessary from the presence of absolutely fresh mud on the top of the moraine which rises to that height above the present ice surface. Former photographs, however, also show this same ridge rising above the ice, though by a less amount than at the present time. As stated above, the past two or three years have been favorable to wasting. As the glacier is now accurately mapped and largely photographed, a few more years may yield the interesting determination whether the present climate of this locality in the Rocky Mountains is capable of supporting a permanent glacier or whether the recently observed shrinkage is a part of its final disappearance.

A second consideration of theoretical significance is connected with the rock terraces several hundred feet high on the sides of the valley below the present glacier (Fig. 1). These plainly indicate an uplift. It is equally plain that the glaciation was not the result of the uplift. The valley cut below these terraces is several hundred feet deep and five hundred to one thousand feet wide. If the glaciation as well as the valley *trenching* resulted from this uplift, then the small stream must have cut out the above-mentioncd valley in the time required for the ice to accumulate after the climate became suited to glaciers.

This assumption is evidently absurd, and it becomes necessary to assume that a considerable interval elapsed between the uplift and the advent of a glacial climate. The supposition may still be made that the glaciation followed close upon another and later uplift. The significance of the observations in this particular terraced valley is not in excluding hypotheses of later uplifts, but in making clear the time relations between the uplift here exemplified and the coming on of the glacier.

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THE FRANCEVILLE (EL PASO COUNTY, COLORADO) METEORITE.

THIS meteorite was bought by Professor F. W. Cragin, of Colorado College, Colorado Springs, Colo., from Mr. David Anderson and wife of Colorado Springs. It was found by Mr. Anderson, as nearly as he can remember, in 1890, about one and one-half miles southwest of the home ranch of Skinner and Ashley, which is east of Franceville. According to Mr. Anderson, it was totally above ground, and there were no signs of any other meteorites.

From the time it was found until purchased by Professor Cragin it had been kept in the home of Mrs. Anderson in Colorado Springs, half-forgotten. It was purchased from Professor Cragin by Ward's Natural Science Establishment, Rochester, New York, in August, 1902. From its external form it is one of the most interesting of the many meteorites that have been in the possession of that firm.

It is a decidedly flattened rhombic pyramid with a somewhat sharp ridge extending around the center of the mass on the four rhombic sides. The dimensions of the mass in these directions are 21×23^{cm} with a thickness of 11.5^{cm}. On one side of this central axis the pyramid projects 6^{cm}; on the opposite side, 5.5^{cm}, as seen in Fig. 2.

The decidedly octahedral form of this iron seems unquestionably due to its separation along natural cleavage planes from a much larger mass; but it is surprising that the form should not have been much more distorted by the erosion due to friction in passing through the atmosphere.

The whole iron is more or less mottled, ranging in color from a reddish-brown to a brownish-black. It is entirely covered with pittings on all sides. Those on what may properly be termed the upper side (Fig. 1) are much more distinct, owing to their size and depth, than elsewhere. Just below the medium ridge on one end there is an unusually large pitting, some 10^{cm}

long and 2^{cm} deep. There are two or three small, but much deeper, finger-like pittings from which troilite has undoubtedly been weathered out.

Two small corners of the mass have been broken off and have the appearance of very old breaks, as the surfaces are entirely oxidized. These surfaces show markedly distinct octa-

FIG. 1.—Upper side, showing pittings. (Two-fifths actual size.)

hedral cleavage. Probably not more than thirty grams have been taken from it since it reached *terra firma.* Two small protuberances, one 2^{cm}, the other 1^{cm} in diameter, were sawed off, and the faces polished and etched. One of these is shown in Fig. 1, the other in Fig. 2. Otherwise the mass was entire until sawed into sections.

Upon slicing the mass but one troilite nodule of any size was found. This occurred on one end-piece and the adjoining slice, and was 14^{mm} in diameter, with two small patches of nickel-

iferous iron in its center. The slices show fractures more or less extending across their surfaces along the natural cleavage faces which are the edges of the kamacite plates, and in some instances the rhombic form produced by the Widmanstätten figures, as is the case in the San Angelo meteorite,[1] are strongly outlined by these fissures.

Upon etching the iron the Widmanstätten figures are readily brought out by acids. These are particularly sharp and clear,

FIG. 2.—Showing pyramidal form. (Two-fifths actual size.)

and of large size, as shown in Fig. 3. The kamacite plates average from 1 to 1.5 ^{mm} in diameter, with an occasional one of 2 ^{mm}. They are unusual in the fact that they extend in an unbroken line in many instances from 90 to 120 ^{mm} in length. The taenite occurs in minute films between the kamacite plates.

The plessite patches are comparatively small for an iron of such coarse crystallization. Some of these patches show no structure when etched, except a slightly pitted surface, while others are prominently made up of alternate layers of kamacite and taenite, producing sharply the so-called Laphamite lines.

Schreibersite is not visible on the etched surfaces microscopically, not even surrounding the troilite nodules, as is usually the case.

[1] *American Journal of Science*, Ser. 3, Vol. V, pp. 269–72.

Mr. John M. Davison, to whom was given 23.9 grams for analysis, reports:

The specific gravity of this siderite is 7.87. A proximate analysis gave:

Soluble in hydrochloric acid, kamacite and taenite,		99.16 per cent.
Combined carbon, not determined.		.....
Undissolved in hydrochloric acid	schreibersite	0.837
	graphite and silicates (trace)	.003
	platinum (from 23.9 grams)	trace
		100.

The analysis of kamacite and taenite together gave	Fe.	91.92 per cent.
	Ni.	8.13
		100.05 per cent.

The weight of this most interesting siderite is forty-one pounds and six and one-half ounces, or 18.3 kilograms.

Colorado has not been prolific in supplying meteorites to the scientific world. As far as noted, there have been but five, including the present iron, all of which are siderites, viz.:

Russel Gulch, Gilpin county - - -	found 1863
Bear Creek, near Denver - - -	found 1866
Jefferson, thirty miles from Denver - -	fell June, 1867
Franceville, El Paso county - - -	found 1890
Mount Ouray, Chaffee county - - -	found 1894

One of these, the "Jefferson (No. 81, Shepard Collection), thirty miles from Denver, Colo.," listed as having fallen in June, 1867, I can find no account of outside of the descriptive catalogue of the meteorite collection in the United States National Museum, January, 1902. It seems apparent that a mistake has been made in labeling this specimen, and it must be dropped as a distinct fall for the following reasons:

The Bear Creek meteorite has been noted in most catalogues as having been found in Denver *county*, Colo., which is also a mistake, as Colorado has no county by this name. The Bear Creek meteorite was first mentioned by Shepard[1] as found upon the eastern slope of the Sierra Madre range of the Rocky Mountains, and Henry[2] notes it as found in a deep gulch near

[1] *American Journal of Science*, Ser. 2, Vol. XLII, pp. 250, 251.

[2] *Ibid.*, pp. 286, 287.

Bear Creek, about twenty-five or thirty miles from Denver. Smith[3] in describing this meteorite gave it the name of Bear Creek. As Denver is on the boundary line between Arapahoe and Jefferson counties, and as there is a Bear Creek extending clear across Jefferson county from west to east, emptying into the Platte, according to Henry's description, the locality of the

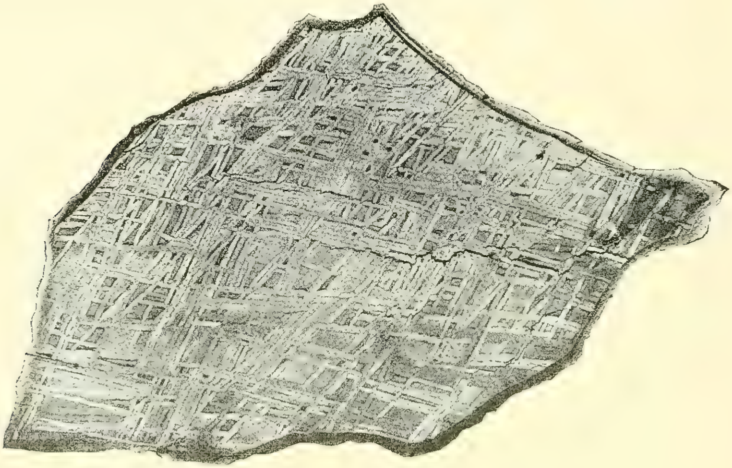

FIG. 3.—Section showing Widmanstätten figures. (Three-fifths actual size.)

Bear Creek meteorite must lie in the west central part of Jefferson county.

Therefore it seems likely that the iron noted in the Shepard Collection as "Jefferson, thirty miles from Denver," is in reality a portion of the Bear Creek meteorite labeled "Jefferson," meaning Jefferson county, and that the date of fall, June, 1867, is an error; particularly so, as the Bear Creek is described by Henry[2] as being "shattered on one end," so that small pieces could be readily detached. "Denver county" has evidently been substituted for "Denver city" in many of the meteorite lists, as no county is given in any of the early reports of the Bear Creek meteorite. Moreover, the Sierra Madre range is west of Denver, and the Bear Creek meteorite is described as having been found on its *eastern slope*, which in all probability

[3] *Ibid.*, Vol. XLIII, pp. 66, 67.

would bring it in Jefferson county. So it would seem best that "Jefferson" should be discarded entirely as a distinct fall and be called "Bear Creek," and that "Denver county" in all meteorite lists should read "*Denver city*." Thus we reduce the Colorado meteorites to four distinct falls.

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STUDIES FOR STUDENTS.

THE MAPPING OF THE CRYSTALLINE SCHISTS.[1]

II. BASAL ASSUMPTIONS.

Introduction.

- Deformation under compressive stresses either by flow or by rupture.
- Deformation zones of the lithosphere.
- Mechanics of deformation by flow.
- Mechanics of deformation by rupture.
- Systems of faults.
- Direct genetic relations of joint systems to systems of normal faults.
- Criteria for recognizing a system of folds.
- Criteria for recognizing a combined system of joints and faults.
- Key areas for determining manner of deformation of a region.
- Nature of evidence for establishing a fault.
- Nature of evidence for establishing a system of faults.
- Method of mapping an area deformed by a system of folds in conjunction with a system of faults.

INTRODUCTION.

IN an earlier paper bearing this general title[2] the writer has discussed the methods of mapping the crystalline schists, and taken occasion to emphasize the necessity for a larger use of outcrop maps for all complexly deformed areas. It was also advocated that many peculiarities of rock exposures besides those ordinarily observed be examined and recorded, and their significance be sought in the final interpretation—the drawing of boundaries and the coloring of the map. In the present paper it is proposed to go somewhat deeper into the subject, and to discuss the basal and perhaps unconscious assumptions of the geologist in the making of his map.

If the writer's contention is upheld, it will be shown that methods of mapping have not kept pace with the advance of

[1] Published with the permission of the director of the United States Geological Survey.

[2] JOUR. GEOL., Vol. X, 1902, pp. 780–92.

the science of geology, and that, whereas the mechanics of crustal deformation, as now understood, and observation alike, take account of two distinct methods of rock deformation, geological mappers seem generally to have regarded but one as possessing much significance. The subject is an intricate one and one which does not readily lend itself to absolute demonstration, but in another place concrete examples will be chosen and described in some detail to show that the subject is a much larger one than is ordinarily understood.

DEFORMATION UNDER COMPRESSIVE STRESSES EITHER BY FLOW OR BY RUPTURE.

The stresses within the earth's crust which bring about sufficiently important deformation to affect the tectonic structure of an area may be assumed to be vertical compression due to the weight of superincumbent material, and lateral compression due to crustal shortening from whatever cause,[1] but in the last analysis a result of gravitation. Tensile stresses are locally produced when rocks assume new attitudes under compressive stress, but their importance as a direct cause of deformation over considerable areas is probably subordinate and largely limited to the effect of temperature change in surface masses of igneous rock, and hence may largely be dismissed from consideration in the present discussion.

The generally accepted classification of displacements resulting from earth stresses has been thus expressed by Suess :[2]

> The visible displacements[3] in the earth's superstructure of rock are the result of movements which proceed from the diminution of volume of our

[1] Van Hise, "Estimates and Causes of Crustal Shortening," Jour. Geol., Vol. VI (1898), pp. 10–64, also, "Earth Movements," *Trans. Wis. Acad. Sci., etc.*, Vol. XI (1898), pp. 465–516.

[2] Suess, *Das Antlitz der Erde*, 1885, Vol. I, p. 143. See also, Margérie et Heim, *Les dislocations de l'écorce terrestre*, Zürich, 1888, p. 8.

[3] The double meaning of the German and French words *Dislocation* and *dislocation* is especially unfortunate. In continental usage "dislocation" is employed in its more general sense for "displacement" (as for example, in the title of Margérie and Heim's work), and quite generally also in a special sense for "disjointing," or equivalent to "faulting." American usage is, I believe, wholly restricted to the word applied in the latter sense.

planet. Strains brought about by this process indicate an inclination to differentiate themselves into tangential and radial strains, thereby inducing horizontal (that is, compressive and folding), and vertical (that is, depressional) movements. Displacements have therefore been separated into two principal groups, by one of which have been produced more or less horizontal, by the other more or less vertical changes of position of portions of the crust.

Under compressive stresses rocks may suffer deformation in one or both of two ways: by flow, when under sufficient load; and by rupture, when the load is insufficient to cause flow.

DEFORMATION ZONES OF THE LITHOSPHERE.

It has been shown that at a depth of 10,000 meters, more or less, even the strongest rocks must find relief from stress by flow, and hence below that depth there must be a zone which, as respects its manner of deformation, may be called the zone of flow.[1] At very moderate depths relief from stress will be obtained by rupture, and this uppermost belt is therefore denominated the zone of fracture. Since, however, the depth at which rocks will flow is dependent primarily upon their crushing strength, there will be an intermediate zone or belt within which deformation will take place partly by rupture and partly by flow (zone of combined fracture and flow). There are many other conditions—such as amount of contained water, elevation of isogeotherms, etc.—which modify the depths of the zone of flow, but they need not be taken up here.

It is clear from these considerations that rocks may be deformed at one period by fracture (when under light loads), and at another time by flow (when below a depth of 10,000 meters, more or less). During a general elevation of a region deformation by flow within a given rock mass, will in general precede that by fracture, and the structures which arise from fracture will be superimposed upon those developed by flow. During a considerable subsidence of a province structures due to flow will be superimposed upon fracture structures and either wholly or partially efface them. The presence in the same

[1] Van Hise, "Principles of North American Pre-Cambrian Geology," *Sixteenth Ann. Rept U. S. Geol. Survey*, Part I (1896), pp. 589–94.

rocks of well-developed flow structures and well-marked fracture structures independent as regards their direction of the flow structures, is strong evidence that the deformation by fracture was subsequent to that by flow. Moreover, in the very nature of the problem it is to be assumed that a fracture structure will in most cases be superimposed upon a flow structure, owing to the fact that degradational forces, as they continuously remove the upper layers of the lithosphere, gradually relieve the load upon the deeply buried rocks, until these are at last exposed to our view. This, however, is not the only reason why we should assume a fracture structure to be the later when found in conjunction with a flow structure, for fracture structures are quickly effaced by flow, whereas flow structures, though disturbed and distorted, are not obliterated by fracture structures.

THE MECHANICS OF DEFORMATION BY FLOW.

The mechanics of this problem is a large subject fully treated elsewhere[1] and may well be largely omitted from this discussion. Deformation by flow produces flexuring or folding of the initially horizontally bedded rocks. The position and the shape of the individual flexures will be determined by many factors: as, the position of old shore lines with their planes of weakness, and the initial dip of the beds resting upon them; the position of masses of igneous material (which by refusing to yield as readily as the bedded rock may elevate a portion of the latter above the zone of flow and cause rupture by thrust at the planes of maximum mashing); the position of earlier planes of rupture or foliation, etc. Flexuring is thus the method by which the heavily loaded rocks accommodate themselves to lateral compression, and results in a crustal shortening and thickening. In every fold there is a local compression normal to the beds in the limbs of the fold, and a local tension in the same relative direction in the arches, the tendency of which is to cause a local transfer of rock mate-

[1] WILLIS, "Mechanics of Appalachian Structure," *Thirteenth Annual Report U. S. Geol. Survey*, Part II, 1891–2, pp. 211–282. VAN HISE, *loc. cit.*, pp. 589–668; see also SUESS, *Antlitz der Erde*, Vol. I, pp. 142–189; MARGÉRIE ET HEIM, *loc. cit.*, 49–87.

rial from the limbs to the arches, the limbs becoming thinner and the arches thicker by this process. Foliation planes, or planes of easy separation, are also produced, which in moderately compressed folds make small angles with the axial plane of the folds,[1] but in closely compressed folds they are approximately parallel to that plane.

MECHANICS OF DEFORMATION BY RUPTURE.

The problem of deformation by lateral compression of a crustal block has been treated from a mathematical standpoint by Becker,[2] his discussion assuming the section of crust to be an elastic solid.

This block may be regarded, then, as subjected to stresses from which it acquires the properties of an anisotropic medium in which the greatest and the least axes of the strain ellipsoid lie in the horizontal plane, owing to the fact that gravity opposes an elongation of the particles in the vertical direction. The effect of such stress is to produce a system of vertical planes of dislocation which in a mass of infinite resistance (perfect elasticity) would make 45° with the direction of pressure, but otherwise (if more or less plastic) the angle would be less. With pressures rapidly applied it is believed that rocks behave like highly elastic bodies. The best evidences that such is the case seem to be furnished by the almost universal observation that the most prominent joint planes are nearly vertical (except in subsequently tilted rocks) and so generally nearly perpendicular to one another;[3] and by the experiments of Crosby,[4] who found that a system strained to a point far below that of rupture (near which plasticity becomes for the first time an important factor) is relieved from its stress by dislocation through shock communicated to the system (for example, by an earthquake). In the

[1] See this JOURNAL, Vol. X, p. 787.

[2] GEO. F. BECKER, "Finite Homogeneous Strain, Flow, and Rupture of Rocks," *Bull. Geol. Soc. Am.*, Vol. IV (1893), p. 50; see also VAN HISE, *loc. cit.*, p. 672.

[3] A. DAUBRÉE, *Études synthetiques de géologie expérimentale*, Part I (Paris, 1879), pp. 300, 301; see also BECKER, *loc. cit.*, p. 73.

[4] W. O. CROSBY, "The Origin of Parallel and Intersecting Joints," *Am. Geol.*, Vol. XII (1893), pp. 368–75.

opinion of the writer, these considerations render invalid many of the data collected from test pieces in laboratories. Elsewhere the writer has developed this subject more extensively.[1] It has there been pointed out that the production of a system of vertical and perpendicular joint planes may be, and probably would be, but the first step in the process of relieving by rupture the stresses within a crustal block. Bv the formation of prismatic joints the potential energy of the system is lowered and a readjustment of the stresses brought about. Furthermore, a tendency is set up favoring local depression, for the reason that rocks in the zone of fracture support their load by their rigidity, and this element of rigidity has been much reduced through the system of dislocations. The crustal block rests upon the rocks in the zone of flow, which are in a condition of potential fluidity, or potential viscosity. The differences of composition and density within the zone of flow, combined with the varying perfection of the joint planes within the zone of fracture (which may be due to lack of homogeneity and perhaps to other causes), furnish conditions for a most irregular and unequal depression of the component blocks produced by the dislocation. On the basis of experiments and observation alike it is believed that the type of tectonic structure produced, before planed down by erosive agencies, may be well illustrated by that of a mosaic, the backing of which has been removed and the component blocks so disturbed as to stand at different altitudes, but with similar axes parallel.

A resumption, or, what is more likely, a continuation, of strong compression of an area in the same horizontal plane, or a second shock communicated to it, would doubtless produce a result of a somewhat different character from the first. The resultant of the lateral compressive stress is by reason of the ready-formed joint-planes resolved in directions parallel and perpendicular to them, the former producing a shear along the planes themselves, and the latter a shear along the diagonals of the blocks of the primary system. Torsional stresses are also set up so as to produce fracturing at the edges of the prismatic

[1] *Twenty-first Annual Report U. S. Geol. Survey*, Part III, pp. 124–33.

blocks. If the direction of the new compression made a large angle with the direction of the first, the directions of the new planes of dislocation would be difficult to determine, and torsion would be at a maximum. If, however, its direction corresponded closely to the first, as is most likely if it occurred in the same general period of disturbances affecting the area, the later planes of dislocation would in their directions bear a simple relation to the earlier. New depression of the area would quite likely follow the new dislocation.

Gilbert has shown that within an area which is undergoing depression along fault planes it is likely that earthquakes will follow one another in succession, owing to the fact that orographic blocks are supported in part by the friction along their vertical walls, and that starting friction is greater than sliding friction.[1] The momentum acquired by the slipping block is effective in reducing temporarily the energy of the system, and time is required for its recovery.

To summarize the mechanics of crustal deformation by rupture, it may be assumed that its result would probably be to produce vertical polygonal prismatic blocks bounded by joint and fault planes in a number (large or small) of parallel series intersecting one another, and that these blocks would stand at relatively different altitudes.

SYSTEMS OF FAULTS.

Continental European geologists have quite generally recognized the importance of systems of normal faults in bringing about important deformations, and have described such systems in many widely separated areas. This may, in fact, be said to constitute the most marked line of cleavage between the structural geological investigations of Europe and of America. The trend of European investigation in this regard was early given by Leopold v. Buch in Germany and Élie de Beaumont in France. The latter correctly located along the Rhine valley[2] parallel

[1] GILBERT, "A Theory of the Earthquakes of the Great Basin, with a Practical Illustration," *Am. Journ. Sci.* (3), Vol. XXVII, 1884, pp. 49-53.

[2] DUFRENOY ET ÉLIE DE BEAUMONT, *Explication de la carte géologique de la France*, Vol. I, p. 398.

lines of faults, and, following the theory of the time, supposed the mountain masses upon either side of the Rhine valley to have been forced up above their former level so as to produce a deep channel. That there are many parallel faults which follow the direction of the valley walls of the Rhine has been abundantly proven by later investigations.[1] Today the presence of numerous dislocations in parallel and often intersecting series[2] has been recognized in many European areas extending from the steppes of southern Russia upon the east, to the Pyrenees upon the west, to describe which there have been brought into use a considerable number of special terms. Some of these terms have no equivalent English expresssion, and such as have are, in some cases, unnecessarily long. Among the foreign terms are: Ger. *Bruchfeld*, Fr. *champs des fractures* (area of dislocations); Ger. *Bruchnetz*, Fr. *réseaux régulier des failles* (fault net-work); Ger. *Senkungsfeld* (sunken area); Ger. *Horst*, Fr. *horst* or *mole* (elevated area left between two or more sunken areas); Ger. *Scholle* (orographic block); Ger. *Graben* (long and narrow sunken block); Ger. *Brücke* (long and narrow elevated block); Ger. *Thurm* (relatively high block of nearly equal basal dimensions); Ger. *Kessel* (relatively low block of nearly equal basal dimensions); etc.

It has been especially the work of Suess to correlate the many scattered observations and in the first volume of his monumental work upon *Face of the Earth*[3] to show how the lineaments of the continent are lines of normal faulting, between which great crustal blocks have been depressed by different amounts. In America the description of what I have called the

[1] DAUBRÉE, *Description géologique et minéralogique du departement du bas-rhin* (Strasbourg, 1852), pp. 384–406; BENECKE and COHEN, *Geognostische Beschreibung der Umgegend von Heidelberg* (Strasbourg, 1881), pp. 595 ff.; AUSFELD *Geologische Skizze der Gegend von Rheinfelden, Mitth. d. Aárg. naturf. Gesell.*, Vol. III (1882), pp. 83–102; etc.

[2] In German usage the term *System* is generally employed to cover any grouping whether of parallel or of intersecting faults. The author has described under the term "*series of faults*" a group of parallel faults, restricting the use of the larger term "*system of faults*" to the network composed of parallel series. *Twenty-first Ann. Report U. S. Geol. Survey*, Part III, pp. 98 ff.

[3] *Antlitz der Erde*, Prag and Leipzig, 1885.

mosaic type of infaulted structure seems to have been restricted to papers upon the Great Basin of the West and upon areas of Newark rocks along the Atlantic border, in both of which provinces only the simplest types of folding are observable. It is highly probable that joints and "minor faults" have been elsewhere frequently observed but thought to have throws so small as to be negligible, the cumulative effects of the small displacements along numerous near-lying planes being overlooked. Faults have too frequently been regarded as isolated phenomena. Within the crystalline areas isolated normal faults have sometimes been supposed to stand in some relation to folds, and because evidence of individual faults is within such areas most difficult to secure, faults have been the last resort of mappers in securing harmony between areal relations and basal hypotheses. The tendency to use faults "to get out of tight places" has probably been in direct ratio to the inadequacy of the hypotheses assumed, and it is, therefore, not strange that faults have been and still are in much disfavor among the most competent and conscientious of American geologists. There are, however, as the writer believes, methods of showing the connection of a *system of faults* with the deformation of an area, through the peculiarities of its joint system, topography, hydrography, outcrop distribution, etc.

It will be the object of this paper to point out especially the methods of recognizing fault systems when in conjunction with systems of folds, because in the manner of deformation of an area is involved the most fundamental assumptions of geological mapping. The view that important deformation may be brought about within a folded area of the crystalline schists by a system of normal faults, has hardly been discussed by American geologists, the system of folds being invariably present and supposed to be the only important manner of deformation exhibited.

The impression should not be gained that in the mind of the writer the relative importance of the two methods of deformation is correctly set forth by the space here devoted to each. Deformation by folding is comparatively well understood and

exploited in the literature,[1] whereas, as pointed out, the consideration of deformations by a system of fractures is, at least for American areas of the crystalline schists, a new departure in geological mapping.

DIRECT GENETIC RELATIONS OF JOINT SYSTEMS TO SYSTEMS OF NORMAL FAULTS.

As early as 1879 Daubrée brought out clearly the relation of normal faults to planes of jointing. As in the case of so many other important discoveries, however, little weight seems to have been attached to the results by contemporary geologists, and it is doubtful if one geologist in ten now records with care the direction of joint planes. His conclusions the eminent French geologist states as follows:

1. The constancy over large areas of the orientation of certain systems of joints has been already confirmed by Sedgwick, de la Beche, John Phillips, and later by other geologists. Further, it has been recognized in Cornwall that the joints maintain their direction in passing from the granite into the schist or *killas* to traverse which they penetrate.

. . . . . This permanence of orientation of the joints . . . . . makes them approach faults, of whose mechanical origin there is no doubt.

It is further known that in many countries joints may be seen passing by various intermediaries into faults properly so called.

2. The direction of joints in Yorkshire has been the subject of a great number of observations of another eminent geologist, John Phillips,[2] who has collected them into a rose of directions: it results that two directions predominate greatly over the others and that the two directions are perpendicular to each other.

3. [Referring to the deformation and distortion of fossils in the vicinity of joints.] . . . . . It is therefore an important result to have arrived at a consideration of joints as the effect of rupture the same as faults, which differ above all by their dimensions.

4. [Referring to the pebbles of conglomerate which have been observed to be neatly cut through by joint planes.] . . . . . A powerful cutting or shearing action has operated in the formation of joints.

To summarize, the characteristic feature which manifests itself in the innumerable fissures of the earth's crust is a parallelism which reproduces itself in the large and in the small fractures—in the fault as in the joint.[3]

[1] See WILLIS, *loc cit.;* MARGÉRIE ET HEIM, *op. cit.;* VAN HISE, *loc. cit.*

[2] PHILLIPS, *Illustrations of Yorkshire*, Vol. II, 1836.

[3] DAUBRÉE, *Géologie Experimentale* (Paris, 1879), pp. 304–6.

A joint becomes a normal fault so soon as displacement occurs along its walls, and the essential difference, therefore, between normal faults and joints may be said to lie in this condition. An area of the earth's crust which has been deformed by jointing under compressive stress is thereby made especially liable to vertical changes of level, because its rigidity, and therefore its competency to uphold its load, has been reduced. Depression of the area, as a whole (and perhaps elevation of certain portions of it), will take place along the joint planes already formed. There is thus, probably, in all cases at least an infinitesimal displacement along the joint walls, and thus no sharp line can be drawn separating joints from faults.

Brögger, in his work upon the Langesund-Skien region of southern Norway, says of the joint and fault system:[1]

> "The dislocations, that is to say, the faults, have in fact cut the landscape through and through, and not alone parallel to one system of lines, but first chiefly parallel to two principal systems, and then also parallel to other less prevalent directions. . . . .
>
> If we consider how thickly the rocks are penetrated by very small faults, it follows, in fact, that a portion of the crust cut up in this fashion is built up like separate rectangular blocks of masonry.

The study in much detail of the circumscribed area of the Pomperaug valley in Connecticut and its vicinity[2] brought out facts quite independent of, but altogether harmonious with those discovered by Brögger in Norway.

In the Connecticut region it was shown that a system of nearly vertical faults falls into a number of intersecting series of parallel dislocations, of which four are quite prevalent, and that the directions of the series bear relations to one another, for which an explanation may be found in the mechanics of jointing under compression. A relation was also disclosed between the directions of the faults and the sizes of the included orographic blocks. It was further observed that the system of faults is parallel to and grades into the system of joints, and like it is

[1] W. C. BRÖGGER, "Spaltenverwerfungen in der Gegend Langesund-Skien," *Nyt Magasin for Naturvidenskaberne*, Vol. XXVIII (1884), p. 401.

[2] HOBBS, "The Newark System of the Pomperaug Valley, Connecticut." *Twenty-first Annual Report U. S. Geol. Survey*, Part III (1901), pp. 1–160.

spaced with an approach to uniformity. As regards the larger displacements of the area, it was found that they seldom occur wholly along one plane, but are distributed over a zone of parallel and near-lying planes — the throw is distributed.

The faults of the less common series run along the diagonals of the larger composite blocks, and are believed to owe their formation to the downthrow of these blocks, and not to the original relief of the area from compression.

CRITERIA FOR RECOGNIZING A SYSTEM OF FOLDS.

While not necessarily present in all areas of disturbed rocks, it is fair to assume that in all areas of the crystalline schists in which bedded rocks are found, folds will be recognizable. The possibility of unraveling their relations to one another within a system will depend upon the intricacy of the structure, the frequency of the exposures, the freshness of the rock, the perfection of a combined joint and fault system, etc.

In general it may be said that flow structures and those produced by fracture are in contrast, the former exhibiting warped (curving) surfaces, and the latter plane surfaces. The courses of the fold structures across the map are, therefore, curved lines, whereas the latter course over the map in straight lines, or in zigzags made up of rectilinear elements. The courses of fault structures upon the map are little disturbed by the relief of the topography in proportion to their inclination — hade, being absolutely unaffected by topography when the hade is 90°. The nature of known formation boundaries upon the map, and that of other structures is thus one of the most important considerations in the determination of the kind of deformation to which the area has been subjected. When alternations of pitch of folds are not present, folded rocks present also rectilinear boundaries, but this consideration loses importance in most areas of intricate geological structure, because evidences of pitch can generally be made out. Change of pitch has been described as characteristic of few areas, because, as already explained, it has until comparatively recently seldom been looked for.

Other indications of the presence of flexures within a given

area are observed at the individual exposures. In areas of folded rocks minor curvings of bedding planes are usually exhibited, and generally in great perfection. Changes in the strike and the dip of the beds are, when large or numerous exposures are found, observed to be, in general, gradual rather than abrupt; and, if abrupt, search will reveal intermediate values for the dip, or the strike, or both, as the case may be. Foliation planes are characteristic of, and connected with, folding, but not with faulting.

CRITERIA FOR RECOGNIZING A SYSTEM OF FAULTS.

The characteristics of a jointed and normally faulted area of the earth's crust have been touched upon in the last section. With abundant outcrops this structure may be disclosed upon the areal map by the generally rectilinear or zigzag boundaries of formations. If not, some indication may be afforded by the prevalence of straight lines and sharp bends in the topography, particularly if the lines fall into parallel and intersecting series. Such a relief may not be apparent without careful examination of the map, for the reason that the particular combination of directions is not known, and it may yet be quite striking when once discovered. Again, the drainage lines may compose a network which in direction conforms both to that of the topographic lines, and that of the formation boundaries. The prominent joints observed at the individual exposures, it may be supposed, will also be in conformity with the directions of the geologic and topographic lines above enumerated. This has never been better expressed than in the classic work of Professor Th. Kjerulf upon the geology of southern and central Norway, which concludes with these words:

Thus the great systems of fissures which cut up the surface produce the primary lines in the aspect of the surface of Norway. The mysterious network of these lines is stamped in indelible characters; this may indeed remain a long time unnoticed; if, however, it has once been seen, it will never again escape observation. Like a moss-grown inscription upon a plate of marble, it is there and may be recognized. Here all embodied representations of plateaus, of tilted plains, and of every sort of erosion have not prevailed to hide the writing or to withdraw it from observation. Push these all aside and

the eye again sees the runic characters, and it depends only upon this, that they all be correctly understood in the future.[1]

The observation of these striking lineaments of the surface, however, unless they be of great perfection, hardly furnishes an adequate demonstration that an important deformation by faulting has occurred. The proof of this must rest upon the discovery of a considerable number of individual faults whose directions relegate them to a system of parallel and intersecting series. The methods by which individual faults may be recognized will be outlined in the sequel.

KEY AREAS FOR DETERMINING THE MANNER OF DEFORMATION OF A REGION.

In geological mapping it is almost an unwritten law that geological sequences must be established at points where formations appear in their larger masses at the surface, it being assumed that structural relations are in such cases the simpler. Areas which show a considerable number of formations brought closely together in small masses at the surface are looked upon with suspicion as areas of local and "minor" faulting, or as containing intercalated beds of unusual types due to purely local conditions of sedimentation. Whichever of these views is assumed, the areas are likely to receive but small attention; first, because the problem of their structure is difficult to unravel and not regarded as affecting the larger questions of the region; and, second, because if once unraveled, the scale of the map would not allow of its representation. Such areas are, therefore, most frequently represented upon the map in the color of the formation which is believed to compose their greater part.

However unsuited these intricate areas may be supposed to be for establishing the order of succession of geological formations, they are nevertheless, it is believed, in many cases the keys (and perhaps the only ones) to unlock the secret of the manner of deformation which has affected the area as a whole. Complicated indeed, they often require only patience and industry for their unraveling, whereas the larger masses by their

[1] *Op. cit.*, p. 334.

very simplicity of areal distribution allow of several hypotheses, any one of which would adequately explain them.

NATURE OF EVIDENCE FOR ESTABLISHING A FAULT.

The several ways in which individual faults may be discovered the writer has elsewhere recited.[1] Some of them are alone sufficient as proof, while others must be regarded as offering incomplete evidence to be weighed in connection with additional observations. As modified for the problem before us these methods will now be considered. Many of them could apply equally to thrusting or to normal faulting, but observation of fault hade will generally be sufficient to determine which in a given case is present.

1. *The observation of beds formed at different times in juxtaposition along a plane transverse to their bedding.*—With conformable formations such an observation may be regarded as absolute proof of a fault, and is, in fact, one concerning which there is no disagreement among geologists. It is only rarely, however, that such a contact will be found exposed, and hence the method serves but seldom.

2. *Offsetting of formations in outcrop.*—Almost equally reliable as a method for determining a fault is the offsetting of formations in outcrop. If in following the mutual boundaries of two formations, the formations are found abruptly thrown to the right or left and continued either along the old or in a new direction, it is only necessary to show that the core of a pitching fold has not conditioned the break of continuity to prove the presence of a cross fault. When several such faults occur in series with throw in the same sense, either the apparent course of the boundary as a whole is given a different rectilinear direction, or a crescentic outline is conditioned. The crescentic ridges which are so prominent a feature of the Connecticut valley are produced in this way. The three ways in which such ridges may be produced by normal faulting have been elsewhere pointed out.[2]

3. *Offsetting of outcrops as definite topographic features.*—With rocks which are resistant to the erosive agencies, or where fault-

[1] *Twenty-first Annual Report, U. S. Geol. Survey*, Part III, pp. 85–93.

[2] HOBBS, *loc. cit.*, pp. 95–8.

ing has been accomplished in a not too early geological time, orographic blocks may cause a distinct offsetting of elevations upon the general surface and display an arrangement in zigzags or *en échelon*, which it is difficult to explain upon any other basis than that of normal faulting. Fig. 1 shows by the outline of the wooded area the serrated border of schist outcrops due to this cause. In Fig. 2 are exhibited four distinct orographic blocks of limestone arranged *en échelon* and owing their position above the general level to a skeleton work of silica which has fitted them to withstand the gnawing effect of erosion.

4. *Dikes.*—It has long been recognized that dikes of igneous or aqueo-igneous rock, and veins whose walls are plane surfaces, represent the positions of either joint or fault fissures which have been subsequently filled. Especially in the Harz mountains of northern Germany has this method of finding the position of old planes of dislocation been successfully employed.

5. *Abrupt changes of strike and dip not indicated in folds.*—An essential characteristic of every folded area is that gradational values can be found to correspond to all important changes of strike or dip, owing to the fact that folds appear in curves in nearly all of their sections (with undulating crests and trough lines in all sections, otherwise in all sections except those parallel to crest and trough lines). With excessively sharp pitching folds, changes of strike and dip by small amounts may be as abrupt as though caused by faults, but search will generally reveal at the apex, in the one case the core of the fold, and in the other the evidences of rupture, although it is quite possible that both will be found together.

6. *Discovery of fault breccia.*—*Reibungs* or fault breccia is very generally found where fault planes of considerable throw are actually uncovered. It is also often found in other places and especially in pits and shafts where access to the wall rock is not possible. Even in these cases, however, it furnishes valuable evidence that faulting has occurred. The formations which are in contact along the fault plane are likely to be indicated by the angular fragments of the breccia, which are usually cemented together by calcareous or siliceous material.

FIG. 1.—Normal faults indicated by offsets of areas of outcrop in the topographic features. View looking north-northwest along the western flank of the Laurel Lake Ridge, Lee, Mass.

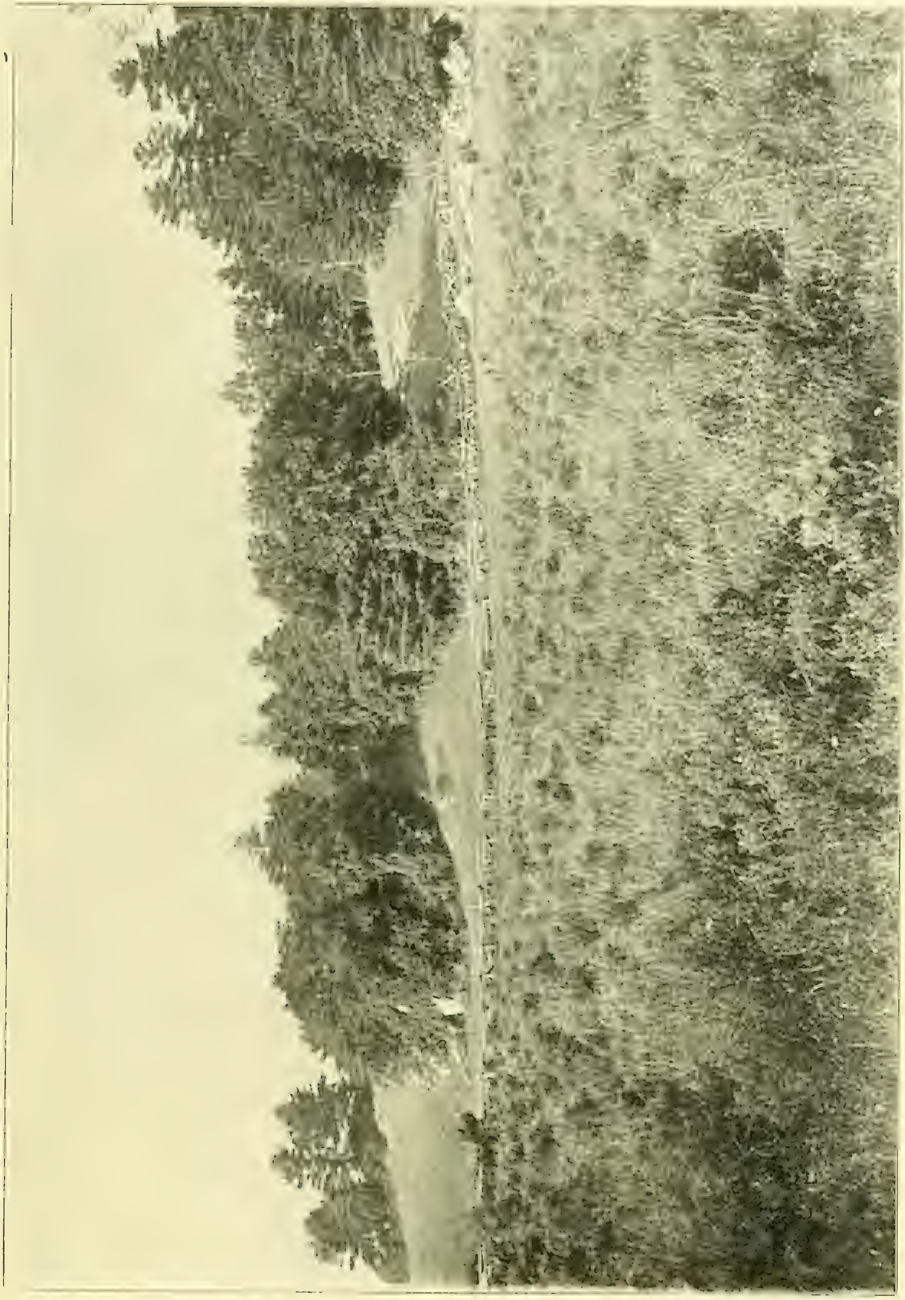

FIG. 2.—Small orographic blocks of silicified limestone arranged *en échelon*. View looking east at a point one and a half miles northwest of Ashley Falls, Mass.

7. *Observation of slickensides.*—While offering contributary evidence in many instances, observation of slickensides is one of the less important methods of locating a fault, and it could hardly be used without other evidence.

8. *Disappearance of outcrops along a rectilinear boundary.*—As already pointed out, little notice seems to have been taken of the way in which outcrops and areas of near-lying outcrops terminate, though in the opinion of the writer such boundaries are full of meaning. When outcrops or groups of outcrops terminate in right lines which are at the same time parallel to the strike of the beds and to the topographic contour lines, no special explanation is required. If they terminate in right lines across the strike of the beds, but along the topographic contour lines, their explanation may be found, either, first, in the erosion history of the region with no dependence upon geologic structure planes; second, in the valley lines as fixed by preexisting fault planes; or, third, in a fault scarp still in evidence at the locality. If the outcrop boundary is a right line and neither parallel to strike of beds nor to topographic contour lines, it is pretty sure to represent the position of a fault plane.[1] In glaciated areas regard must, however, always be had to essentially local and irregular accumulations of drift as affecting this explanation.

9. *Occurrence of scarps in the more resistant rock.*— In certain areas, at least, of the crystalline schists in which there is accentuated topographic relief, scarps are among the commonest of the physiographic features. In the mapping of the hard-rock geology account has, however, rarely been taken of them, it being perhaps rather generally assumed that their interpretation is the special field of the physiographer and glacialist. If, however, it can be shown that their directions conform to planes of jointing and faulting, their study will furnish some of the most fascinating and instructive lessons for the geologist in the crystalline areas. It is doubtless because their secrets lie hidden in the structure of the underlying rocks that rock scarps as topo-

[1] See HOBBS, *loc. cit.*, pp. 89–91 for special cases of faults fixed by rectilinear boundaries of outcrop.

graphic features have received so little consideration at the hands of the modern school of physiographers.

The perfection of rock scarps will doubtless be dependent primarily upon the resistance of the rock of which they are formed to the agencies of erosion, and to the time that has elapsed since their formation. In dense basalt their life is probably the longest, and the present surfaces will most nearly represent the original fracture planes. It is a fact of general observation that scarps are usually interrupted in such a way as to produce a step-like structure, which suggests in nearly all cases that the throw was distributed over several parallel and near-lying planes. The great cliffs of the Newark basalt of the Connecticut valley produced in an unknown period of post-Newark time, furnish striking illustrations of rock scarps in great numbers and perfection.

The evidence that precipitous rock walls are connected genetically with the fault and joint system of a region — an inherently probable supposition — must be drawn from a study of the direction, not of a single cliff, but of a large number of scarps embracing a considerable area. Accurate topographic maps are most instructive in this regard, but they fail to tell the full story. Photography here comes to the aid of the geologist, not only in recording topographic peculiarities, but in the exposition of them. To give to photographs their full sphere of usefulness, however, it is important to indicate upon the map from what points they were taken and the pointing of the camera at each locality. A photograph common and uninteresting in itself becomes full of meaning in its relation to the map. A character like Fig. 3 entered upon the map and consisting of a circle which incloses the point at which the view was taken, and proceeding from the circle a short arrow to show the camera pointing, will supply the needful information. A figure within the circle refers to the number of the photograph or to the plate of a report, as the case may be.

Fig. 3.

Scarps may, however, be produced in other ways than by faulting. Other agencies most potent to produce them are:

first, in glaciated regions the ice mantle which has carried away blocks from the lee side of elevations lying in its path; and, second, in regions of severe climate, the frost, which has separated blocks and allowed them to roll down steep slopes. A special cause of scarp formation may be the undermining by solution of beds of calcareous rock, which has allowed the overlying beds to fracture and fall. In all cases, however, some earlier structure planes must be assumed along which the block has separated, and these planes may have been either planes of jointing, or faulting, or foliation, or of original bedding. Considering each scarp by itself, therefore, and quite independent of the system of the region, it is more likely to represent a fault in proportion: first, as it does not face in the direction in which the ice mantle moved over the area; and, second, as it is not parallel to a plane of fissility or of bedding (not parallel to the strike).

Study of the southern New England area has shown that cliffs of considerable extent which adhere to a uniform trend often for long distances usually do so, not along a single plane, but by a series of minor zigzags the elements of which are joints or faults of other series combined with the one which corresponds in direction with the general trend of the cliff.[1] Fig. 4 will illustrate the manner in which it is accomplished. Such a composite cliff is shown in Fig. 5. Figs. 1 and 10 must be regarded as showing the same type of structure, but in the next higher orders of magnitude, respectively, within a composite series. This observation of the composite nature of lines of dislocation is regarded as of much significance in showing the genetic connection of faults and joints, as well as in reading the geological structure of an area.

Fig. 4.

10. *Fault gorges.*—In many places, and especially throughout New England, are found deep clefts in the harder rock which are locally known as "purgatories," "devil's dens," "ice-glens," "ice-gorges," etc. The walls of these clefts are nearly or quite

[1] *Vide* BRANNER, "Geology in its Relation to Topography," *Trans. Am. Soc. Civ. Engineers*, Vol. XXIX (1898), p. 63.

FIG. 5.—Cliff essentially rectilinear in direction produced by faulting and composed of many faults of a lower order of magnitude. Southeast wall of the Cobble, Tyringham, Mass. The wall trends N. ± 38° E. for nearly a mile, the smaller faults striking N. ± 38° E., N. ± 70° W., N. ± 10° W., etc.

perpendicular, and their bottoms are occupied, not by a stream, but by an accumulation of great angular blocks composed of the same material as the walls. Deep below this accumulation of blocks one may sometimes thread his way until the ice and snow of the preceding winter are found unmelted even at the end of summer. Such gorges find their simplest explanation in the local depression of a long and narrow orographic block along vertical joint walls (*Graben*), with the accompaniment of much fracturing and dislocation in the block itself. (See Figs. 6 and 7).

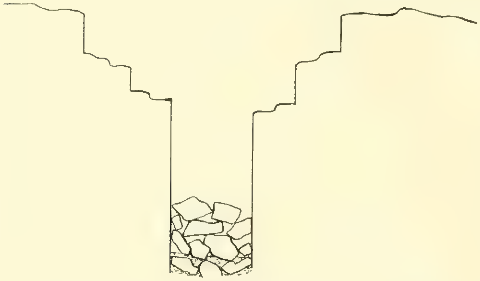

FIG. 6.—Cross-section of fault-gorge (so called "ice-gorge") near Hartsville, Mass. The stippled area represents snow and ice.

11. *Arrangement of surface springs in right lines.*—Since the time of Daubeny and Forbes the locations of springs have been connected with fissures. Peale in his report upon the mineral waters of the United States cites many regions where springs are arranged along fault planes, and, speaking of the Great Basin, says: "A map of the hot springs of the Great Basin would be, to a great extent, a map of its displacements."[1] Regions might be multiplied where essentially the same facts have been observed.

NATURE OF EVIDENCE FOR ESTABLISHING A SYSTEM OF FAULTS.

Observed faults are in parallel and intersecting series—Having made out within a region the presence of a number (larger or smaller) of normal faults, it is next to be determined whether they stand in any relation to one another If a considerable number have been observed, it is likely that some will be found to be parallel, or as nearly parallel as the errors of observation allow. Evidence of this nature is, however, valuable in propor-

[1] PEALE, *Fourteenth Ann. Report U. S. Geol. Survey*, 1894, Part II, pp. 63, 64; see also RUSSELL, *Fourth Ann. Report U. S. Geol. Survey*, 1884, p. 452; HILL AND VAUGHAN, *Eighteenth Report, ibid.*, 1898, Part II, Plate XLVI; HOBBS, *Twenty-first Report, ibid.*, Part III, pp. 91–3.

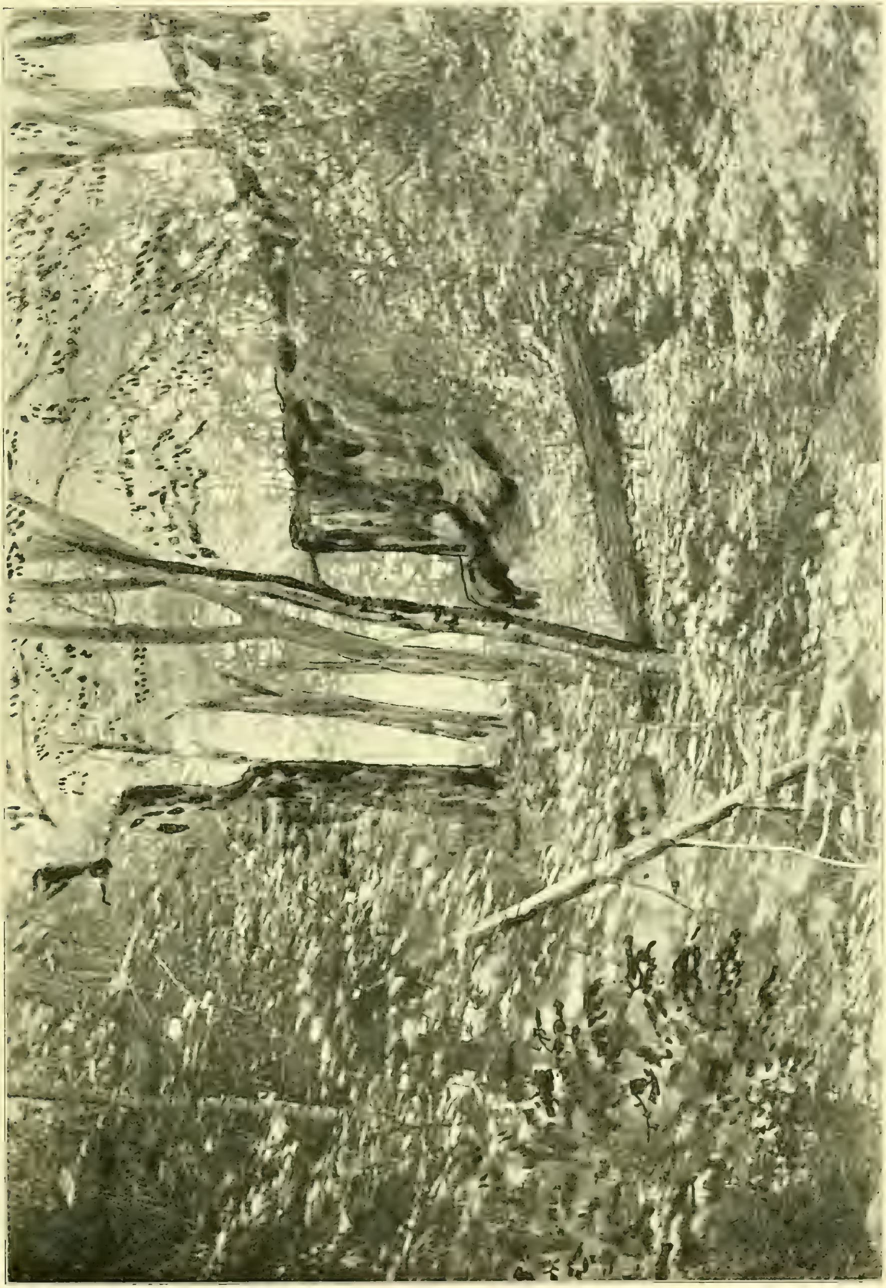

FIG. 7. — A gorge produced by faults. The "Ice Gorge" near Hartsville, Mass. The view is from within the gorge and looks toward the entrance.

tion as the number of observed faults is large. It has been observed in the Pomperaug valley and fully confirmed by experience gained subsequent to the publication of the report upon that area, that a regular spacing of normal faults is as characteristic of them as it is of joints. It is, therefore, often possible to determine not only the shape but the size of orographic blocks included between series of normal faults within a system or network.

2. *Observed faults are parallel to the joint system.*—In this observation lies the most important evidence that the region as a whole is affected by a system of normal faults genetically connected with its system of joints. Not only is it to be observed whether the two systems are parallel, but, if so, it is to be noted whether any simple relation connects the direction of the individual joint and fault series with the dimensions of the orographic blocks which they have conditioned.

3. *Zigzag topography.*—The study of the topographic map supplemented by observation and by photographs made in the field may show that the physiographic features are bounded by straight elements which coincide in direction with the network determined by the joints and faults. Figs. 9 and 10 represent topography of this type, the one from the intricately faulted Newark area near Meriden, Conn., the other from the crystalline belt of Berkshire county, Mass. A good illustration also of this type of topography is Monument Mountain in Berkshire county, whose main mass is composed essentially of a single fairly uniform formation and is believed to owe its exceptionally rugged topographic development almost solely to its joint and fault planes. (See Fig. 8.)

In the paper which has here been so frequently cited for illustrations of fault structures the writer has used the expression "floating block topography" in reference to a very striking physiographic development, by which are revealed orographic blocks, generally of similar size and shape standing at different altitudes and with bounding fault-planes in evidence as scarps. Fig. 11 displays such a type of physiographic relief. It is to be noted that the blocks of this type (for convenience "unit"

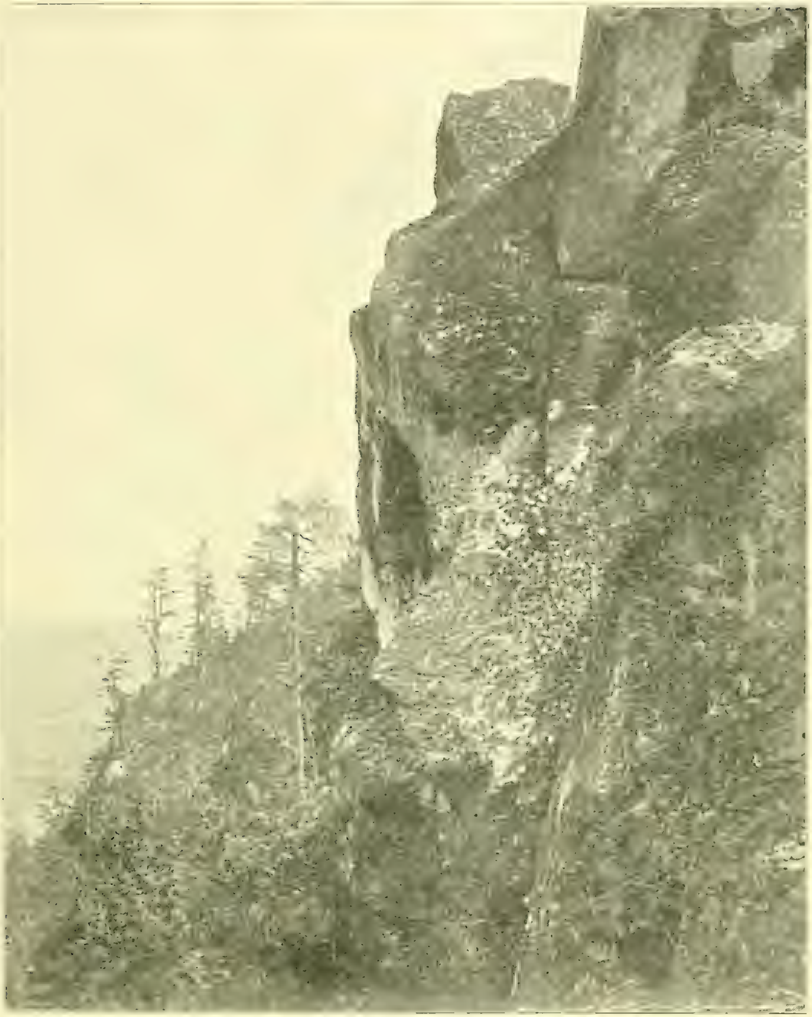

FIG. 8.—Details of topography of Monument Mountain, near Stockbridge, Mass.

blocks, though subdivided by faults and joints) are sometimes grouped into hills—composite blocks—which are spaced over the general surface much like the black squares of a checker board. Fig. 11 exhibits about two-thirds of such a hill in a series of the kind described. Fig. 2 is a detail taken from another hill of the series.

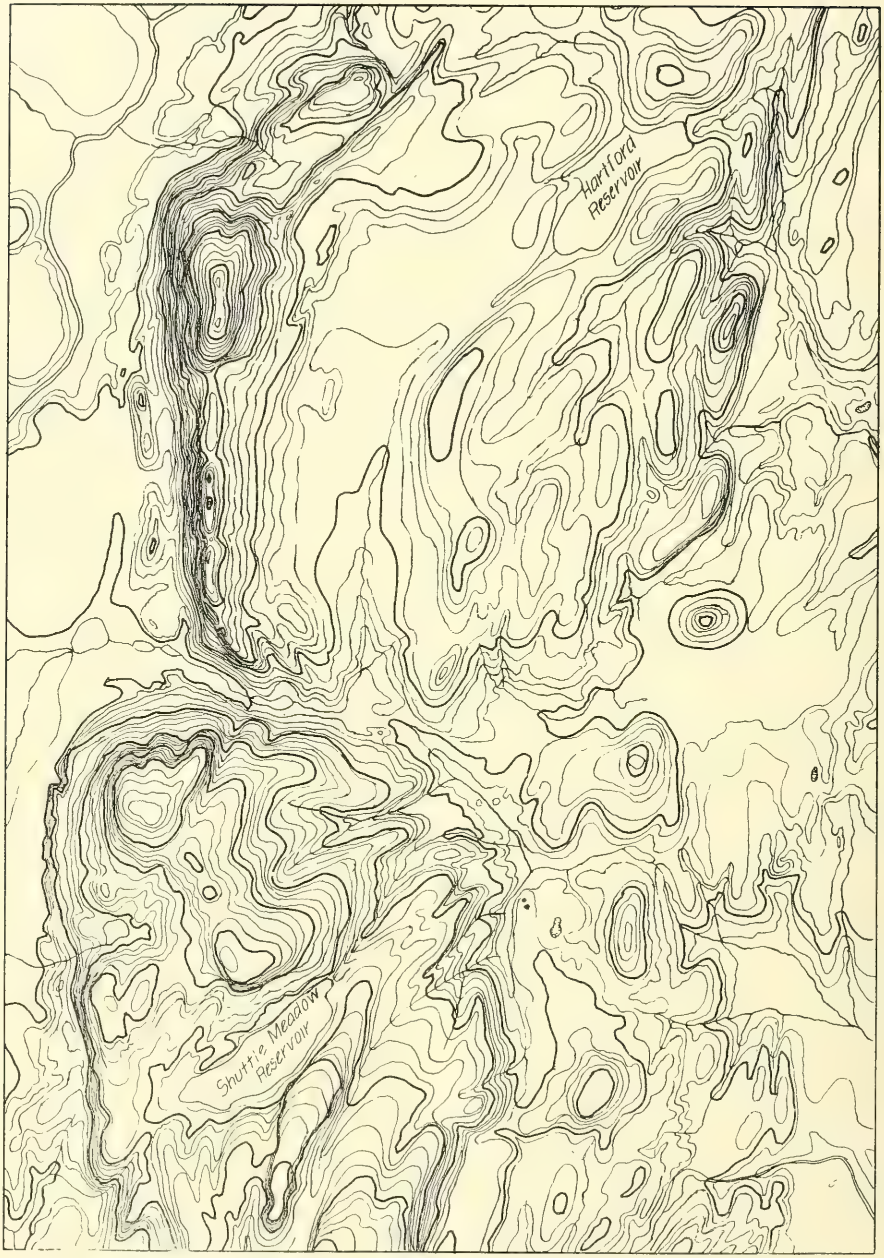

Fig. 9.—Zigzag topography of unfolded but normally faulted Newark rocks. Scale one inch equals one mile. From the Meriden sheet of the map of Connecticut by the U. S. Geological Survey.

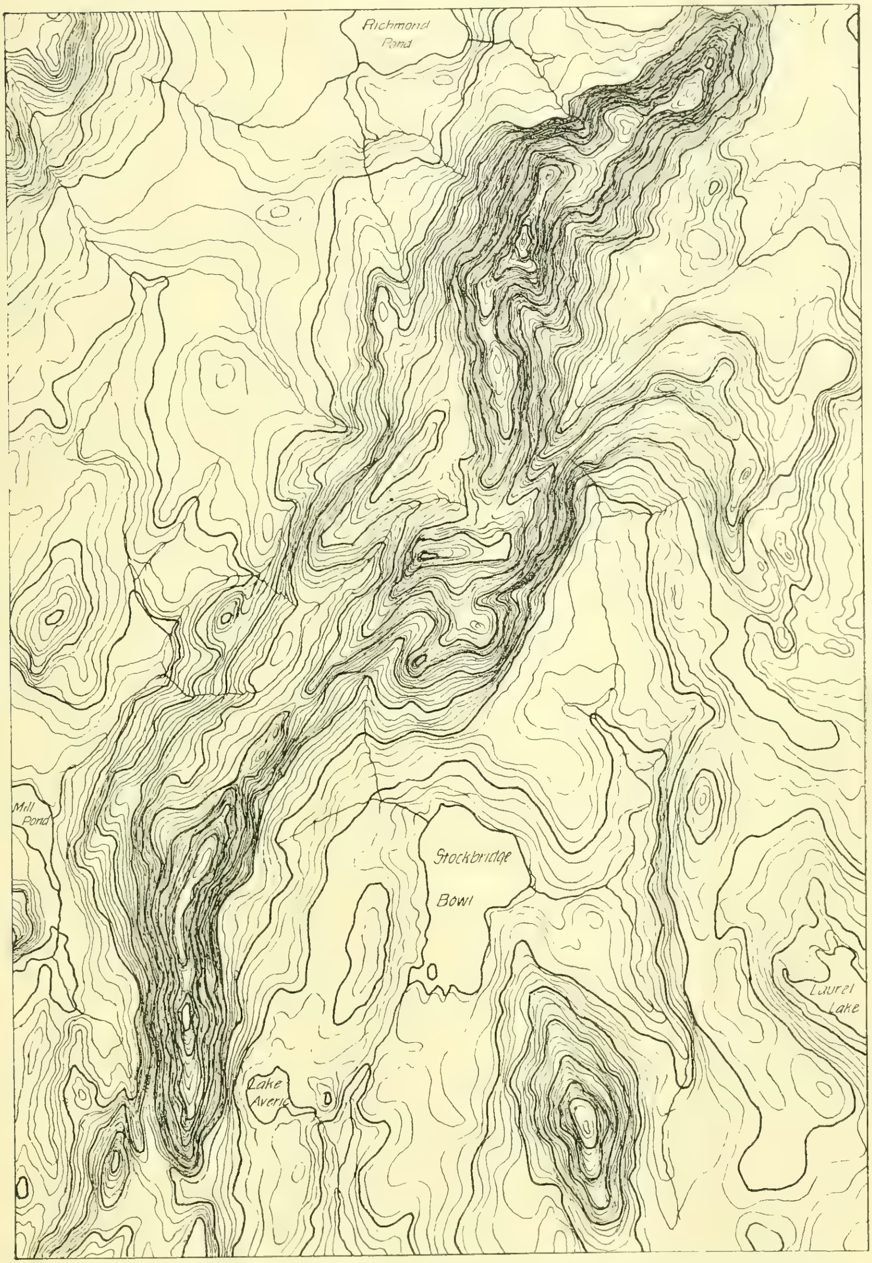

FIG. 10.—Zigzag topography in the crystalline schists. Scale one inch equals one mile. From the Pittsfield sheet of the map of Massachusetts by the U. S. Geological Survey.

4. *The drainage system a network of parallel and interesting series.*—The recognition of the fact that a system of joints and faults has been responsible for the present directions of streams within any region, aside from purely theoretical considerations of the closet naturalist, must be credited to Professor Theodor Kjerulf, the former director of the Geological Survey of Norway. His study of the newer and accurate topographic maps of the country led him to see in the courses of the valleys, lakes and fjords, the lines of dislocations.[1] The occurrence in many areas of similarly regular networks of streams in which the elements are essentially straight lines in parallel series over considerable distances has now long been known, and has been given an adequate explanation by Daubrée as conditioned by the system of fractures (*lithoclases*) of the region, in part by the faults (*paraclases*) and in part by the joints (*diaclases*).[2] Daubrée cites the works of many geologists to show that such stream networks have been observed in many widely separated areas. Since the appearance of his work (1879), numerous other examples have been added.[3] Löwl, in his work on valleys,[4] treats the subject under three heads—fold valleys, fault valleys, and erosion valleys. He mentions the Rhine and the Leine in Germany and the Piave in the southern Alps, as well as other valleys, which are of the fault type.

Daubrée appears to ascribe the orientation of the larger number of stream channels to joints rather than faults, his view

[1] KJERULF, *Geologie des südlichen und mittleren Norwegens*, auth. German ed. by AD. GURLT (Bonn, 1880), pp. 328–34. See, however, in this connection, STUR, "Das Isonzothal," etc., *Jahrb. d. k. k. geol. Reichsanst.*, Vol. IX (1858), pp. 324–66, and plate.

[2] DAUBRÉE, *Géologie experimentale* (1879), pp. 332–73.

[3] SUESS, *Antlitz der Erde*, Vol. I (1885), p. 339. BRÖGGER, "Spaltenverwerfungen in der Gegend Langesund-Skien," *Nyt Magasin for Naturvidensk.*, Vol. XXVIII (1884), pp. 253–419. "Ueber die Bildungsgeschichte des Kristianiafjords," *ibid.*, Vol. XXX (1886), pp. 99–231. KEMP, "Preliminary Report on the Geology of Essex County," *Report of State Geologist of New York for Year 1893*, Albany, 1894, pp. 438–40. VAN HISE, "Origin of the Dells of the Wisconsin." *Trans. Wis. Acad. Sci.*, Vol. X (1895), 556–60. HOBBS, *loc. cit.* chap. v., also "The River System of Connecticut," JOUR. GEOL., Vol. IX (1901, pp. 469–85).

[4] LÖWL, *Thalbildung* (Prag, 1884), pp. 19–43.

FIG. 11.—"Floating block" topography. Northwest of Ashley Falls, Mass.

being that the course of the stream has been conditioned by the gaping of the joint fissure, and he finds in some instances that the beds on opposite sides of the stream stand at the same level. Löwl takes account of the lateral translation of streams working in inclined strata, and argues that the bed of the stream does not represent the position of the fault, which in many cases can be observed high up upon the slope. Speaking of the valley of the Oder in the Harz mountains, a stream which follows the direction of the Oder fault, he says :

> The Oder valley is therefore nothing more than a performance of the flowing water. Its course along a line of disturbance proves only that this directed the erosion into a definite course.

The writer, by taking account of the great number of parallel faults within a series, would ascribe the courses of the streams within a network more largely to the presence of many long and narrow down-thrown orographic blocks (*Graben*), which have conducted the water like canals.[1] Upon this assumption the equal altitude of the strata upon opposite sides of a valley does not preclude the probability of faults along the bed of the channel. Whatever explanation be offered of the directing of streams upon a large scale by joints and faults, there can be no doubt that streams are of greatest service to the geologist in showing the *directions* rather than the *positions* of lines of dislocation. Regular networks of streams may be assumed to be much more common than the literature of the subject would indicate, for the reason that comparatively little attempt has been made to explain stream directions on the basis of structure planes of the underlying rocks.

5. *Zigzag course of coast lines.*—Evidence of the same kind as that derived from drainage systems is sometimes to be supplied by coast lines, which may disclose the lineaments of a submerged drainage system, the border of a sunken composite orographic block, or a margin of areas of outcroppings. The coast of Scotland between Sutherland and Ross furnishes an illustration.[2]

[1] *Twenty-first Ann. Report U. S. Geol. Survey*, Part III, p. 149, Pl. XVI., JOUR. GEOL., Vol. IX, p. 483.

[2] JUDD, "The Secondary Strata of Scotland," *Quart. Jour. Geol. Soc.* (1873), pp. 131, 134, Pl. VII ; see also SUESS, *op. cit.*, Vol. I, p. 269.

It should be by a consideration of all the above outlined methods that the presence or absence of a fault system should be determined for any given area.

METHOD OF MAPPING A CRYSTALLINE AREA DEFORMED BY A SYSTEM OF FOLDS IN CONJUNCTION WITH A SYSTEM OF FAULTS.

The discovery that the beds within a region of crystalline schists have assumed their present attitudes in consequence of deformation of the area by a system of folds in conjunction with one of normal faults, greatly increases, it must be admitted, the difficulties in the way of accurately setting forth the geology upon maps. The question may well be asked whether even with patience and industry the areal distribution of formations can be adequately represented. Where outcrops are abundant and well distributed, and where formations are sharply differentiated petrographically, the difficulties can be overcome; but where gneiss, schist, and quartzite types by reason of gradational members are with difficulty distinguished, even under favorable conditions, their appearance in a fault mosaic will in many cases defy the most skillful worker to unravel.

To fix the order of succession of formations, it will be necessary, not only to exclude the possibilty of an overturn (as by finding the arch of a cross fold), but actually to follow one formation beneath the other.

In other ways the problem of mapping will be simplified. The appearance of formations, first in one areal succession, and again in a different succession not to be accounted for by overturning, will find an adequate explanation. Upon the theory that folding alone has accomplished the deformation of an area of crystalline rocks, geological sections have been strained literally and figuratively beyond the point of rupture. The mechanics of folding is now pretty well understood, and the appearance in geological sections of synclines which have one limb several times the thickness of the other (a not uncommon means of adjusting to theory) finds, it is believed, as little warrant in mechanics as it does in observation.

In explaining an intricately faulted area on the basis of deformation by folding only, it is also the tendency to make geological formations much more heterogeneous than they really are, until at last they have so many different phases that all distinguishing petrographic differences are lost. With the broader interpretation petrography will take a higher place in geological mapping.

It is the intention of the writer in another place to present with the aid of maps and photographs some concrete examples of areas within the belt of crystalline schists where deformation has been accomplished in part by folding and in part by a system of faults.

WILLIAM HERBERT HOBBS.

MADISON, WIS.
September 1, 1902.

Reviews.

PRE-CAMBRIAN SUMMARIES FOR 1901.

Van Hise[1] describes the geology of the Lake Superior iron ore deposits. The general succession of formations in the iron-bearing districts appears in the following table:

Mesabi.	Penokee-Gogebic.	Vermilion.
Keweenawan: Great basal gabbro and granite, intrusive in all lower formations.	Gabbros, diabases, etc.	Great Gabbro.
Upper Huronian (Mesabi series): Virginia slate (upper slate formation). Biwabik formation (iron-bearing formation). Pokegama formation (quartzite and quartz-slate formation).	(Penokee-Gogebic series): Tyler slate (upper slate formation). Ironwood formation. (iron-bearing formation.) Palms formation (quartz-slate formation).	Animikie series: Upper slate formation. Gunflint formation (iron-bearing formation).
Lower Huronian: Granite intrusive in lower formations. Slate-graywacke-conglomerate formation. (Equivalent to the Ogishke and Knife formations of the Vermilion district.)	Bad River limestone (cherty limestone formation).	Intrusives. Knife slates. Lower Huronian iron-bearing formation. Ogishke conglomerate.
Archean: Greenstones, hornblende schists, and porphyries.	Granite and granitoid gneiss. Schists and fine-grained gneiss.	Vermilion series: Intrusive granites, porphyries, and greenstones. Soudan formation (the iron-bearing formation). Ely greenstone, an ellipsoidally parted basic igneous and largely volcanic rock.

[1] "The Iron-Ore Deposits of the Lake Superior Region," by C. R. Van Hise, assisted in Mesabi and Vermilion sections by C. K. Leith and J. Morgan Clements respectively, *Twenty-first Ann. Rept. U. S. Geol. Surv.*, Part III, 1901, pp. 305-434; with geological maps.

Marquette.	Crystal Falls.	Menominee.
Upper Marquette: Michigamme formation (locally replaced by Clarksburg volcanic formation). One might divide Michigamme sedimentary formation into three parts: (*a*) upper slate member, (*b*) iron-bearing member, (*c*) lower slate member. Ishpeming formation, consisting of two members; the Bijiki schist (in western part of district), and the Goodrich quartzite, containing detrital ores at its base.	Michigamme formation, containing an iron-bearing horizon not separated in mapping for much of the district, but in a southeastern part having as lower formations (*a*) the Groveland formation, and (*b*) the Mansfield slate.	Upper Menominee: Hanbury slate, bearing in lower portions calcareous slates, etc., containing siderite and iron oxide. Vulcan formation, consisting in descending order of three members: (*a*) Curry member (iron-bearing); (*b*) Briar slate; (*c*) Traders member (iron-bearing).
Lower Marquette: Negaunee formation (the chief iron-bearing formation). Siamo slate, containing inter-stratified amygdaloid. Ajibik quartzite. Wewe slate. Kona dolomite. Mesnard quartzite.	Hemlock formation. Negaunee formation (in northeastern part of the district). Randville dolomite. Sturgeon quartzite.	Lower Menominee: Negaunee formation (in small patches). Randville dolomite. Sturgeon quartzite.
Granite, syenite, peridotite. Kitchi schist and Mona schist, the latter banded, and in a few places containing narrow bands of iron-bearing formation. Palmer gneiss.	Granite.	Granites and gneisses. Quinnesec schist.

Van Hise and others[1] have discussed the geology of the Lake Superior region in previous reports, both general and detailed. The present report is a summary of the earlier reports,

[1] See especially "Principles of Pre-Cambrian Geology," in *Sixteenth Annual Report*, Part I, *U. S. Geol. Surv.*; pp. 571–874; *Bulletin* No. 86, *U. S. Geol. Surv.; Monographs U. S. Geol. Surv.*, Vol. XIX, XXVIII, XXXVI; and *Folio U. S. Geol. Surv.*, No. 62.

but it contains in addition many new features of interest. Attention will be directed only to such conclusions as are new or vary from those given in the preceding reports.

In the Vermilion district the great Stuntz conglomerate and equivalent rocks have been found to lie unconformably under the Animikie series, which has been referred to the Upper Huronian by the United States Geological Survey, and thus the Stuntz conglomerate is correlated with the Lower Huronian series instead of with the Upper Huronian, as in former reports. The underlying greenstones, green schists, and iron formation, the latter of sedimentary origin, are thus thrown into the Archean.

In the Mesabi district the Keewatin of the Minnesota Survey, which was in large part classed as "Archean" by the United States Geological Survey and recognized by all as being unconformably below the Animikie, is subdivided on the basis of recent work in the district by C. K. Leith into an upper series of graywackes, slates and conglomerates, correlated with the Lower Huronian, and a lower basement complex, consisting mainly of greenstones and green schists, correlated with the Archean. This correlation is based on the equivalence of the Animikie with the Upper Huronian long maintained by geologists of the United States Geological Survey.

In the Marquette district certain jaspers and associated cherty and slaty rocks found intimately associated with the basement rocks of the Archean, and previously supposed to be Huronian rocks infolded with the Archean, are now themselves called Archean.

In the Michipicoten district of Canada the iron formation, and associated greenstones and green schists, are correlated respectively with the iron formation with associated greenstones and green schists of the Vermilion district, and are therefore classed as Archean.

The iron ores of the Lake Superior region are supposed to have originated from iron carbonate in all districts outside of the Mesabi. In the Mesabi district the ores have mainly resulted from the alteration of a green ferrous silicate in small granules

as first shown by Spurr, but the ores have come also in small part from the alteration of iron carbonate which is correlative in origin with the green granules. The ferrous silicate granules are believed not to be glauconite, as they were named by Spurr.

Comment.—The reference to the Archean of sedimentary iron formation rocks in the Vermilion, Michipicoten, and Marquette districts is a source of surprise and comment among many interested in pre-Cambrian stratigraphy. The term "Archean" has been consistently used by the United States Geological Survey for the "basement complex" of the Lake Superior region, consisting essentially of igneous rocks, and all pre-Cambrian sedimentary rocks have been referred to the Algonkian. In survey reports on Lake Superior geology there have been slight variations from this usage, for certain "tuffs" and "gneisses" (Kitchi and Palmer) classed as Archean in the Marquette district have been referred to as partly sedimentary. In the present paper Van Hise has gone a step farther and included sedimentary formations of considerable importance in the Archean. The basal complex rocks of igneous origin are very closely associated with sedimentaries, and in many areas scarcely to be discriminated in the mapping. On the other hand, both igneous and sedimentary rocks are sharply separated by a profound and conspicuous unconformity from sediments called Huronian or Algonkian. In mapping in the Lake Superior region it has been found convenient, and in many cases necessary, to class together all rocks, igneous and subordinately sedimentary, below this well recognized unconformity at the base of the Huronian. Van Hise has chosen to retain the term "Archean" for this structural unit. It is thought by many geologists that it would have been preferable to have extended the term "Algonkian" to include the sediments beneath the well recognized Huronian, thus adding one more series to the Algonkian, keeping in the Algonkian all recognizable sedimentary rocks beneath the Cambrian, and leaving the term Archean for the true igneous basement complex (if there be such a thing). If, because of the close association of the basement igneous rocks and the sedimentary rocks beneath the Huronian, it were found desirable to consider the basal igneous

and sedimentary rocks together as a structural unit under one term, the same geologists suggest that some local term might have been applied to the basal complex in the Lake Superior country instead of the general term "Archean."

The correlation of the upper series of the Mesabi and Penokee-Gogebic districts (which are agreed by all to be equivalent to the Animikie series) with the Upper Huronian of the original Huronian area of the north shore of Lake Huron, first worked out by Logan and Murray, is also questioned by certain Canadian and Minnesota geologists, who believe that these series are younger than the true Huronian of the original Huronian area. They would correlate Van Hise's Lower Huronian with the Upper Huronian of the original Huronian area, and thus Van Hise's Archean would in large part fall into their Lower Huronian.

Finally, it is maintained by Canadian geologists and others that the granites classed by Van Hise as Archean are intrusive into the Huronian rocks. Van Hise's position is that the granitic complex contains rocks both older and younger than the Huronian sedimentary rocks; that the fact that certain granites are clearly intrusive into the sediments does not militate against the evidence offered by basal conglomerates that another, and perhaps larger portion, is really unconformably below the Huronian rocks.

It would not be possible in a summary of this nature fully to summarize the arguments and reasons which have led Van Hise to the conclusions outlined in the above paper. He has in preparation a final monograph on Lake Superior geology in which these and allied questions are fully discussed in the light of recent developments. In view of Van Hise's close and exhaustive work in the Lake Superior region, which is in many respects a type pre-Cambrian region, and the long period of time during which this work has been carried on, his final statement of his position with reference to the geology of the area will be awaited with interest.

Coleman[1] reports on an examination of the "Lower Huronian"

[1] "Iron Ranges of the Lower Huronian," by A. P. COLEMAN, *Tenth Report of the Bureau of Mines*, Ontario, 1901, pp. 181–212.

iron ranges at Shining Tree Lake, Clear Lake, Sault Ste. Marie, Aberdeen Additional, Batchawana Bay and northward, Michipicoten Harbor, and the Helen mine, all in Ontario. As a result of this work it is possible to greatly extend the areas of Lower Huronian iron formation rocks in Ontario. Their general distribution is stated by Coleman as follows:[1]

It has long been known that the Vermilion iron range of Minnesota crossed the boundary into Ontario at Hunter's Island, and jaspery iron ores have been found at various points in that region—e. g., by W. H. C. Smith on Jasper Lake, where banded jasper and hematite have a width of forty or fifty feet. Brecciated jasper and iron ore are known from the Mattawin region also, and from a number of points to the north, as noted by Dr. Bell; but in the latter case the deposits may be of Animikie age, and therefore not to be included here.

In the band of Huronian mapped as running eastward from Lake Nipigon in the direction of Long Lake, a deposit of banded jasper and iron ore has been examined by Mr. J. Watson Bain, near the mouth of Black Sturgeon River, and an extension of it is reported from the same stretch of Huronian, north of Long Lake. To the south of this, ten or twelve miles from the mouth of Pic River, the other type of deposit is found, brecciated granular silica with magnetite.

The Michipicoten range is separated from this by a wide area of Laurentian, and the first outcrop occurs about fifteen miles west of Iron Lake, near the headwaters of Dog River. It is jaspery and cherty, with interbanded magnetite and hematite; but on the eastward extension of the line across Dog River one finds the granular variety mixed with magnetite near Paint Lake. A few miles to the north what appears to be a parallel band has been traced by Professor Willmott and has been found to include promising ore deposits. The whole extent of this range, as traced by Professor Willmott, is about twenty-seven miles, the longest continuous stretch in Ontario.

Farther to the east not much has been reported until Magpie River is crossed by Speight's east and west base line, where a range of hills with jaspery and cherty material interbanded with ore runs two or three miles southeasterly. Six or eight miles to the south the iron-bearing rocks are found again near Park's Lake, and can be followed four or five miles west and southwest, including the promising Josephine mine now being developed. In the same direction is Lake Eleanor, where siderite and the banded silica are found; and two miles west is the Boyer Lake property described before, the band having a length of about a mile and a quarter and running east and west. Ten miles to the southwest is the Gros Cap deposit of sandy and

[1] Pp. 200–202.

quartzitic rock interbanded with hematite, sunk upon many years ago, but not developed to any great extent as a mine. Rock of the same sort has been found near Michipicoten Post and Cape Choyé, Professor Willmott having ascertained the latter range to be six miles long, though without ore so far as known.

Once more a wide band of Laurentian intervenes, the next examples of the iron formatian occurring sixty-five miles to the south, near Batchawana Bay, where two bands run nearly parallel to one another, about east and west, each from four and a half to five miles long, with reported finds some miles to the east on Harmony River, and to the west near Pointe aux Mines on Lake Superior. The two bands differ in character, the one to the south being of jasper with hematite and that to the north cherty or quartzitic with magnetite.

The next known locality, about nine miles northeast of the Sault, is of the same character as the last, and is enclosed in Laurentian rocks instead of Huronian or basic eruptives as in most other localities. The wide band of Huronian between the "Soo" and Sudbury is not known to contain any rocks of the iron formation, though the large numbers of bright red jasper pebbles in the conglomerates of the upper Huronian must have a source somewhere in the region.

In the considerable area of Huronian north of Woman River, on the main line of the Canadian Pacific railway, jaspery iron ore has been reported, but no details have been obtained regarding it. To the east of this Mr. Whitson has examined a jasper range running several miles in a southeasterly direction, between the upper end of Onaping Lake and Meteor Lake; and about twenty-five miles to the northeast is a range of jasper, chert and impure siderite with magnetite and limonite of the Shining Tree Lake region, running somewhat west of north and south of east for three and a half miles, and perhaps for double that distance. A few miles farther northeast jasper is reported from one of the chain of lakes belonging to Montreal River, and still farther to the north at Night Hawk Lake.

In the southern portion of this Huronian region rocks of the kind occur on the northwest shore of Lake Wahnapitae as dull red jasper and chert with magnetite, and extend west in the Laurentian in Hutton and Wisner townships. It may be that there are two separate bands here, the southern one east and west and the northern one north and south, the latter the more important, as containing what are said to be large deposits of magnetite.

Of the iron range to the northeast of Lake Wahnapitae, Professor Miller reports that "starting from Lake Temiscaming on the east the first outcrop, which is of small size and was not visited by me, is situated a short distance east of the east end of Rabbit lake. The next outcrops occur along the northeast shore of the east end of the northeast arm of Lake Temagami, the band here stretching from near Snake Lake west to Tetapaga. Outcrops

occur also near the end of Matagama Point. A belt lies parallel to these outcrops to the northward and runs, with breaks here and there, from near the west side of Net Lake to Kokoko Lake.

"Then there is an isolated belt stretching from near Cross Lake, north of west, past the southern extremity of the south arm of Temagami to the south-west arm of the same sheet of water, and to the westward outcrops are found on Emerald Lake. A band, more or less broken, runs along the north of Lake Wahnapitae northwest into and through part of the township of Hutton."

He adds that "in nearly all cases the iron ore, magnetite, is intimately interbanded with jasper, which varies much in color in different parts of the field. In some outcrops the magnetite is pretty massive, and if situated near a railroad could apparently be worked profitably. The breadth of the band of interlaminated material is sometimes 500 feet or more. It is at times much bent and fractured, having been disturbed by igneous intrusions, and some of these disturbed bands give evidence of being worthy of more careful prospecting than we are able to do in the limited time at our disposal."

Belts of iron-bearing rocks, like those described in this report, are found also in Quebec, though up to the present little has been done in searching them out. Mr. McOuat has reported from the eighth portage of the Quinze, on the headwaters of the Ottawa above Lake Temiscaming, an ore which forms "layers from the thickness of paper to about an inch, and is interlaminated with similar layers of whitish-gray and dull red fine-grained quartzite. The iron ore constitutes probably from a fourth to a third of the whole, and as the thickness of the whole band is about thirty feet, the total thickness of the layers of iron ore would probably not be less than eight feet." This is evidently the same type of deposit as those described from Ontario.

Mr. A. P. Low describes jaspery iron ores which he compares with those of Michigan, and also cherty iron carbonates from various points in Labrador, and probably some of these occurrences are Lower Huronian, though from his description it is clear that most of them are of Animikie age.

From the statement just given it will be seen that bands of jaspery cherty, or sandstone-like rock interbanded with magnetite, hematite, or limonite and sometimes associated with siderite, occur from point to point across the whole of northern Ontario, with lengths varying from a hundred feet to twenty-seven miles. Almost all of the important areas mapped as Huronian have more or less extensive belts of this rock, and in several cases isolated patches or strips of it occur in the Laurentian, as if these were remnants left when less resistant Huronian rocks had disappeared. These portions contained in the granite are never red jasper, but generally cherty or quartzitic, and the iron ore is magnetite, whereas in Huronian areas we generally find jasper or granular silica with hematite or limonite.

Associated with the iron formation rocks above mentioned,

and also in other areas, are conglomerates containing numerous fragments of iron formation rocks, and therefore believed to be of Upper Huronian age. In addition to the conglomerates whose distribution was described in a previous report,[1] conglomerates are known in the following areas:

The Doré[2] river conglomerate, which contains many pebbles of sandstone and chert, has been found to extend within a few miles of the Helen mine, and to be about twenty-four miles in length from the mouth of Dog River on the west where it begins. In sections of some of the pebbles siderite has been found, proving that materials exactly like those at the mine were rolled on the inter-Huronian beach before the conglomerate was formed. Similar conglomerates have been found at other points in this Huronian area; for instance, two or three miles north of Coetz Lake, not far from the Josephine mine.

Conglomerates have not yet been found nearer the Batchawana jasper and chert beds than at the north end of Goulais Bay, fifteen miles to the south, where Murray mapped jasper conglomerate many years ago. The extensive bands of quartzitic conglomerate containing blood-red jasper pebbles in the original Huronian region, extending from Lake George almost to Thessalon, about thirty miles, and found in several different bands, some of them quite to the north of those mapped by Murray, have never been accounted for, since no jasper has been found nearer than Batchawana, more than fifty miles to the northwest, and there the jaspers are much duller in color. The accompanying black chert pebbles, which are equally common, might have been supplied by the cherty iron ore band nine miles northeast of the Sault Ste. Marie, mentioned in a previous part of this report, though this is about ten miles from the nearest of the conglomerates. The region is, however, little known beyond the few miles of settled country along the St. Mary's River and the north shore of Lake Huron, and future exploration may solve the problem.

Numerous conglomerates occur along the same stretch of Huronian to Sudbury, but no jasper or chert pebbles are known in them, though they are found in quartzites and graywackes somewhat farther east on Lake Matagamashing, not far from the jasper iron ore belt north of Lake Wahnapitae. Small amounts of jasper conglomerate have been noted northward from this, and a graywacke conglomerate containing jasper and chert pebbles extends for some miles parallel to the Shining Tree Lake iron range but a mile or two to the west.

East of Lake Wahnapitae conglomerates with jasper are known at various points to Lake Temiscaming, and also on the Quebec shore of that lake

[1] *Bureau of Mines*, 1900, pp. 180-86, and *Bull. G. S. A.*, Vol. XI, 1900, pp. 107–14. See Summaries, JOUR. GEOL., Vol. IX, 1901, pp. 447-9.

[2] Pp. 203–4.

near Baie des Perés. That they extend still further to the east, is shown by Low's report on Labrador, where conglomerates with Laurentian bowlders and jasper bowlders and pebbles seem to be common.

It is not certain, of course, that every one of these rocks containing pebbles of jasper, chert, or sandstone is a basal conglomerate of the Upper Huronian, but many of them undoubtedly are, and in the majority of cases the source of their pebbles is found in adjoining bands of siliceous iron-bearing rocks which may be looked on as belonging to a horizon near the top of the Lower Huronian, Van Hise's Mareniscan.

Willmott[1] describes the geology of the Michipicoten area northeast of Lake Superior. He makes the succession from the base up as follows:

1. Lower Huronian green schists. Some of these are undoubted lava flows showing the characteristic elliptical structure described by Clements as occurring in the Hemlock formation of the Crystal Falls district. At a number of points agglomerates are found, as at Little Gros Cap fish station, north of Goetz Lake, east of Manitowoc, and elsewhere. Commoner occurrences are the various green schists, chlorite, hornblende, mica, and sericite schists. Presumably all these schists are derived from lavas, basic and acidic. The dip of the schists is always nearly vertical and the strike follows closely the line of contact with the granite, to be described later.

2. Lower Huronian sediments. The most characteristic of these is a belt of ferruginous chert, which has been found at intervals for about sixty miles. This rock consists of banded hematite and silica with usually some residual carbonate of iron. The bands vary from one-tenth of an inch in thickness up to several inches. The silica is sometimes very like loaf sugar; again it is like quartzite, chert, or jasper. Red jasper is not infrequent. The hill at the back of the Helen mine is a huge mass of siliceous carbonates. The rocks, as a whole, and the mode of occurrence of the ore, are strikingly like the Lower Huronian iron formations of Marquette and Tower. Besides the iron formation, beds of carbonaceous shales and limestones have been recognized at several points. Shale occurs interstratified

[1] "The Michipicoten Huronian Area," by A. B. Willmott, *American Geologist*, Vol. XXVIII, 1901, pp. 14–19.

with the ferruginous chert at Iron Lake. Near Paint Creek and at Eleanor Lake it has also been found. Whether it always underlies the iron formation is undetermined, but it probably does not. The cherty limestone has been traced in a fairly continuous line from the Helen mine to the east of Park's Lake, a distance of twelve miles.

3. Upper Huronian sediments. These consist of schist-conglomerate. Coleman describes the bowlders as "granites most frequently, then quartzites, or sandstones with pebbles generally small, next green schists, then felsite schists and porphyroids, and finally a few gneisses, but none of the Laurentian type." A thin section of one of the quartzite pebbles showed considerable carbonate, proving that it undoubtedly came from the iron formation. This conglomerate has been traced pretty continuously for thirty-eight miles in a semicircular belt around the central granite boss. At many points, as at Iron Lake, Dog River, Doré River, Wawa Lake, it contains pebbles from the very characteristic iron formation. This fixes its age as Upper Huronian.

4. Laurentian granite, intrusive in the Huronian rock. The granite is in undoubted eruptive relations with the conglomerate along the shore of Superior, for example a few miles west of the Doré. A mile and a half up the Magpie, a boss of granite is in eruptive contact with the conglomerate, and although it may not be of the same age as the larger boss three miles to the northwest, it probably is. In the opposite direction a succession of granite gneiss bosses intrusive in the schists are found, for six miles, after which the granitoid gneiss occurs without interruption for over a hundred miles.

Comment.—Van Hise[1] has referred Willmott's "Lower Huronian" green schist and iron-bearing formation to the Archean, and has referred his "Upper Huronian" schist-conglomerate series to the Lower Huronian. Indeed he would so refer most of the conglomerates described as Upper Huronian by Coleman in the article above summarized. The Michipicoten series show close similarities in structure and lithology to portions of the Archean and Lower Huronian series, respectively, of the Ver-

[1] See summary of Van Hise's report on a preceding page.

milion iron-bearing district of Minnesota. There is little dispute as to the equivalence of the series in the two districts, but there is dispute as to their correlation with the original Huronian series of the north shore of Lake Huron, and thus as to their nomenclature. At the east end of the Vermilion district they have been proven to underlie unconformably the Animikie series of the Mesabi district and its eastward continuation to Thunder Bay on Lake Superior, which has been correlated by Van Hise and others with the Upper Huronian of the original Huronian area, but which the Canadian geologists and others regard as younger than the true Upper Huronian. As already noted, Van Hise has in preparation a final monograph on Lake Superior geology in which the position of the United States Geological Survey with reference to the correlation of these series in the light of recent work will be fully stated.

Bain[1] describes the iron belt of Lake Nipigon, devoting his attention mainly to economic and petrographic features. The stratigraphical features are covered in the general report of Coleman summarized on a previous page.

Miller[2] describes the iron ores and associated rocks of the area adjacent to Lake Temegami and of the Lake Wahnafutae and Hutton areas to the west, all in the Nipissing district of Ontario. The Temegami has been previously mapped and reported upon by A. E. Barlow.[3] Miller's discussion of the general geology of this area follows that of Barlow, with minor additions and corrections.

Winchell[4] publishes a geological atlas of the state of Minnesota with synoptical description of plates. This volume contains maps and general conclusions found in Volumes IV and V of the Minnesota Survey, summarized in this JOURNAL, Vol. IX, pp. 79–86. One additional map is published, a general geological map of the state.

[1] "The Iron Belt on Lake Nipigon," by J. W. BAIN, *Tenth Report of Bureau of Mines*, Ontario, 1901, pp. 212–14.

[2] "Iron Ores of Nipissing District," by WILLET G. MILLER, *Tenth Report of the Bureau of Mines*, Ontario, 1901, pp. 160–80.

[3] *Annual Report Geol. Survey of Canada*, Vol. X, Part I, for 1897, pp. 302. Summerized, JOUR. GEOL., Vol. VIII, 1900, pp. 439–41.

[4] *The Geological and Natural History Survey of Minnesota*, Vol. VI, 1900–1.

Duparc[1] describes the copper-bearing (Keweenawan) rocks of the northwest extremity of Keweenaw Point, Michigan. The article is throughout merely a summary of previous reports on this area by the geologists of the Michigan and United States Survey, and this moreover without a single reference to such reports.

Hall[2] describes the Keweenawan rocks south and southwest from Duluth, along the St. Louis and St. Croix rivers, and shows that a series of alternating lava flows and sediments lie in a synclinal northeast-southwest trough, the western border of which is marked by a profound fault. To the east of the fault the Keweenawan rocks are highly tilted to the southeast, while to the west of it the Cambrian rocks are much broken up. The relations of the fault to the distribution of the flows and analogy with other volcanic regions seem to show that the fault was a plane of weakness along which most of the lavas were originally erupted. The faulting was pre-Cambrian, Cambrian, and post-Cambrian, as shown by the fact that in some places the Cambrian rests horizontally upon the upturned Keweenawan rocks, and in others is much broken up.

Hall[3] describes and maps the slates and associated rocks in the vicinity of Cloquet and Carlton on the St. Louis River, and certain hornblendic and micaceous schists associated with granite and diabase to the west along the Mississippi and Snake rivers. He maintains that the slates and graywackes to the east and the hornblendic schists to the west belong to one and the same series, and that the schists have resulted from the metamorphism of graywacke and slate by the intrusion of granite. Still later intrusions of diabase have cut both the granites and the slates. Accepting Spurr's statement that the Carlton slates are Keewatin or Lower Huronian, the con-

[1] "Note sur la Region Cuprefere de l'extremite Nord-Est de la peninsule de Keweenaw (Lac superieur)," par LOUIS DUPARC, *Archives Sci. Physique et Nat.*, Tome X, 1900, p. 21.

[2] "Keweenawan Area of Eastern Minnesota," by C. W. HALL, *Bulletin of the Geological Society of America*, Vol. XII, 1901, pp. 313–42, Pls. 27–28.

[3] "Keewatin Area of Eastern and Central Minnesota," by C. W. HALL, *Bulletin of the Geological Society of America*, Vol. XII, 1901, pp. 343–76, Pls. 29–32.

clusion is reached that the schists to the southwest are Lower Huronian, and that the intruding granites are post-Lower Huronian. If this conclusion be correct, the granites and schists of the central and eastern portions of Minnesota must be mapped as Algonkian rather than Archean, as in the past.

Ami[1] briefly summarizes the salient features of the geology of the principal cities of eastern Canada, including St. John, Ottawa, Quebec, Montreal, and Toronto.

Ami[2] summarizes the geology of Canada, and indicates the meaning and correlation of the principal terms employed in Canadian geological nomenclature.

Ells[3] sketches the development of geological work in the province of Quebec.

Ells[4] describes and maps the geology of the Three Rivers sheet of the "Eastern Townships" map, Province of Quebec. Archean rocks occupy most of the northwestern portion of the area north of the St. Lawrence River. A portion of this area, including anorthosite masses, has previously been described by Adams.[5]

The great mass of the rocks seen pertain to the Grenville series, rather than to the so-called "Fundamental" gneiss. The composition of the Grenville series, with its crystalline limestones and with rusty gneiss bands, very closely resembles that met with in the lower Ottawa district, but the calcareous members are much less widely developed. There are also large areas of anorthosite, red granite, augen-gneiss and masses of green pyroxenic diabase. Quartzite is an important component of this series, and large areas of this rock, similar to that found along the

[1] "On the Geology of the Principal Cities of Eastern Canada," by HENRY M. AMI, *Trans. Royal Soc. of Canada*, Vol. VI, 1900; sec. iv, pp. 125–64.

[2] "Synopsis of the Geology of Canada," by HENRY M. AMI, *Trans. Royal Soc. of Canada*, Vol. VI, 1900, sec. iv, pp. 187–225.

[3] "Problems in Quebec Geology," by ROBERT W. ELLS, *Record of Science*, Vol. VII, 1898, pp. 480–502.

[4] *Geol. Surv. of Canada, Annual Report*, New Series, Vol. XI, for 1898, pp. 5 J–70 J; with geological map.

[5] *Geol. Surv. of Canada*, Vol. VIII, Part J. Summarized, JOUR. GEOL., Vol. VII, p. 401.

Ottawa, are found associated with the gneiss as far north as the northern limit of the map-sheet.

The definition of the so-called fundamental gneiss is, as a matter of fact, not always possible in this district. If the latter appears at all, it must be along the crests of some of the numerous north-south anticlines, which are generally low, the rocks over a large area being inclined at low angles. The prevailing gneiss is a grayish and hornblendic variety, generally quartzose, and with frequent bands in which garnets are abundant.

The anorthosites are intrusive in the Grenville series. The Grenville series are correlated with the Hastings series and both are equivalent to the Huronian. The Fundamental gneiss is Laurentian.

Bell[1] describes and maps the geology of the Baffin Land shore of Hudson Strait.

The rocks of the northern side of Hudson Strait from North Bay to Chorkback Inlet and inland to Lake Mingo consist of well stratified hornblende and mica-gneiss, mostly gray in color, but sometimes reddish, interstratified with great bands of crystalline limestones, parallel to one another and conformable to the strike of the gneiss, which in a general way may be said to be parallel to the coast in the above distance. The direction, however, varies somewhat in different sections of the coast. All are of Laurentian age.

The distinguishing feature in the geology of the southern part of Baffin Land is the great abundance, thickness and regularity of the limestones associated with the gneisses. At least ten immense bands, as shown on the accompanying map, were recognized, and it is probable that two others, discovered in North Bay, are distinct from any of these. There would, therefore, appear to be twelve principal bands as far as known, to say nothing of numerous minor ones, between Icy Cape and Chorkback Inlet. Their total thicknesses may be 30,000 feet, or an average of 2,500 feet for each of the principal bands. These rocks are correlated with the Grenville.

[1] *Geol. Surv. of Canada, Annual Report,* New Series, Vol. XI, Part M, for 1898, pp. 5 M–38 M; with geological map.

Low[1] describes and maps the geology of the south coast of Hudson Strait and the west and south shores of Ungava Bay. Granite and gneiss of various ages occupy three-fourths of the coastal area. Associated with them are gabbros, diabases and other greenstones, cherts, quartzites, shales, and slates. All are provisionally referred to the Archean.[2] Flat-bedded Cambrian rocks rest with apparent unconformity upon the crystalline complex.

Tyrrell and Dowling[3] describe and map the east shore of Lake Winnipeg. The rocks are all Archean and the great preponderance of gneisses and granites of the Laurentian is the chief feature. Small areas of Huronian greenstones and schists occur in two localities, one on Lac du Bonnet and the other at the mouth of Wannipegow River.

In an account of a trip from Edmonton through Yellow Dog Pass, in the Rocky Mountains, to Canoe River a tributary of the Columbia River, McEvoy[4] describes and maps Shuswap rocks, of Archean[5] age, occurring on Mica Mountain near the western end of the route. The series includes dark glittering mica-schist, easily weathering, thinly foliated garnetiferous mica-schist, with a high percentage of mica and garnet, hard garnetiferous mica-schist in massive beds, bands of dark fine-grained micaceous rock apparently of eruptive origin, and layers of fine-grained gneiss which, in some instances at least, is certainly intrusive. The whole series, while differing somewhat from the Shuswap series of the southern interior of British Columbia, shows the main characteristics of that series and may be classed as such. The age of this series as given by Dr. Dawson is Archean.

[1] *Geol. Surv. of Canada*, *Annual Report*, New Series, Vol. XI, Part L, for 1898, pp. 5 L–47 L; with geological map.

[2] Pre-Cambrian.

[3] *Geol. Surv. of Canada*, *Annual Report*, New Series, Vol. XI, for 1898, pp. 5 G–98 G; with geological map.

[4] *Geol. Surv. of Canada*, *Annual Report*, New Series, Vol. XI, for 1898, pp. 5 D–44 D; with sketch map.

[5] Pre-Cambrian.

Dawson[1] describes the geology of the Rocky Mountain region in Canada. The oldest rocks of the region belong to the Shuswap series of Archean[2] age. The Shuswap series characterizes considerable areas of the Selkirk, Columbia, and adjacent ranges in the southern part of British Columbia. It is known also in the Cariboo mountains and near the sources of the North Thompson and Fraser, about latitude 53°. It is again well developed on the Finlay River, where the country has been geologically examined, between the 56th and 57th parallels of latitude. Northward to this point these rocks appear to be confined to a belt lying to the west of the Laramide range and to come to the surface seldom, if at all, in that range. Further north similar rocks occur in the Yukon district in several ranges lying more to the west, but still with nearly identical characters, in so far as they are known. The Shuswap series includes highly metamorphosed sediments with perhaps the addition of contemporaneous bedded volcanic materials. They are grayish mica-gneisses, with some garnetiferous and hornblendic gneisses, glittering mica-schists, crystalline limestones and quartzites. Gneisses in association with the last mentioned rocks often become highly calcareous or siliceous and contain scales of graphite, which are also often present in the limestones. These bedded materials are, however, associated with a much greater volume of mica-schists and gneisses of more massive appearance, most of which are evidently foliated plutonic rocks, and are often found to pass into unfoliated granites. The association of these different classes of rocks is so close that it may never be possible to separate them on the map over any considerable area. The granites may often have been truly eruptive in origin, but the frequent recurrence of quartzites among them in some regions indicates that they are at least in part, the result of a further alteration of the bedded rocks. The original bedded portions of the series closely resemble those of the Grenville series of the

[1] "Geological Record of the Rocky Mountain Region in Canada," address by the President, GEORGE M. DAWSON, *Bulletin of the Geological Society of America*, Vol. XII, 1901, pp. 57–92.

[2] Pre-Cambrian.

Province of Quebec, and the associated gneisses resemble the Fundamental Gneiss of the same region. The greatest thickness of the Shuswap rocks so far measured, where there is no suspicion of repetition, on Kootenay Lake, is about 5,000 feet, but even here there are doubtless included considerable intercalations of foliated eruptives.

Schrader[1] describes certain granites and schists seen in a reconnaissance along the Chandler and Koyukuk rivers of Alaska. These are referred to as "basal" and certain of the schists are correlated with Spurr's Birch Lake series of schists, but no attempt at further correlation is made.

Brooks[2] describes the Archean of the Tanana-Yukon divide. A broad belt of crystalline rocks extends in a northeast-southwest direction in the region of the Tanana-Yukon divide, embracing a series of gneisses, mica-schists, basic schists, and various intrusives, chiefly of an acid character. Near the middle Tanana this series bends to the west and south, and its continuation is to be sought for in the region of the upper Kuskokwim. To the southeast this belt is probably continued by the granitic rocks on the Pelly River, described by Dawson. What evidence we have goes to show that this is the basal series of the Yukon Basin, and as it contains no recognizable detrital material it can properly be assigned to the Archean. Whatever the original character of the rocks may have been, they are now essentially mica-schists and gneisses, with considerable intrusive material. Their metamorphic condition is the strongest argument for considering them older than any of the sedimentary rocks.

Comstock[3] reviews the stratigraphy of Arizona. Granites, gneisses, and schists, probably of pre-Cambrian age, occur at

[1] "Preliminary Report on a Reconnaissance along the Chandler and Koyukuk Rivers, Alaska, in 1899," by F. C. SCHRADER, *Twenty-first Ann. Rept. U. S. Geol. Surv.*, Part II, 1901, pp. 441–86; with sketch map.

[2] "A Reconnaissance from Pyramid Harbor to Eagle City, Alaska, Including a Description of the Copper Deposits of the Upper White and Tanana Rivers," by A. H. BROOKS, *Twenty-first Ann. Rept. U. S. Geol. Surv.*, Part II, 1901, pp. 331–91; with sketch map.

[3] "The Geology and Vein Phenomena of Arizona," by T. B. COMSTOCK, *Trans. Am. Inst. Min. Eng.*, Vol. XXX, 1900, pp. 1038–1101.

various places, but have not been thoroughly studied. The massive granites are exposed in a limited tract surrounding Prescott, including Granite Mountain, and farther southwest in the Grand Canyon of the Colorado, in the valley of the Colorado in Yuma county, and in the Little Dragoon Mountains, Cochise county. These massive granites form a basement for the other rocks of the region.

In a number of places are found fissile granites which appear to lie between the massive granites and the schistose strata which form the floor of much of the area of western Arizona.

Schists are well exposed in northwestern Arizona, in Mohave county, with E.-W. strike, tilted at high angles. Very similar exposures occur in other districts, as near Oracle and Mammoth, in Pinal county; in tracts in Pima county, and in portions of Yuma county. In Graham and Cochise counties, and, to a less extent, in Gila county, with occasional outcrops near the adjoining boundary of Maricopa and Yavapai counties, the same trend is prominent. Erosion has exposed portions of the same terrane, thrown into the N.E.-S.W. trend, in limited areas in Graham and Yavapai counties, and, possibly, in the northeast portion of Yuma county.

Blake[1] describes the salient features of the geology of Arizona. The Santa Catalina, Rincon, and Rillito mountains consist largely of granitic gneisses and schistose rocks of pre-Cambrian age with a highly complex folded structure, and exhibiting a high degree of metamorphism. Taken together, these mountains may be regarded as the main axis of ancient uplift, and of insular land areas in the pre-Cambrian and Paleozoic periods, the beginning of the "Arizona Land."

The gneiss of the southern side of the Santa Catalina near Tucson is regarded as Archean. It is remarkable for its regularity of stratification and its great thickness, probably over 10,000 feet. It occurs in great tabular masses made up of thin layers which, when seen laterally, give the appearance of evenly strati-

[1] "Some Salient Features in the Geology of Arizona with Evidences of Shallow Seas in Paleozoic Time," by WILLIAM P. BLAKE, *American Geologist*, Vol. XXVII, 1901, pp. 160–67.

fied shales and sandstones. In the same range, but on the northeastern side, facing the valley of the San Pedro, another formation of thinly bedded and highly crumpled mica schist in sharply defined zigzag folds is referred to the Huronian, and is given the name Arizonan.

Hershey[1] describes the schistose rocks of the Klamath Mountains in northwestern California. On the whole it seems impracticable to fix upon any particular part of the time between the Archean and the Devonian as the period of deposition of the Klamath schists, but it is believed that the evidence favors the earlier or Algonkian portion rather than the Cambrian or Silurian portion.

Spencer[2] describes Algonkian rocks occurring in the center of the Rico Mountains of Colorado. They consist of quartzites, quartzitic schists, and biotite and actinolite schists. The exposed thickness of the quartzites is over 350 feet and probably as much as 500 feet. The relations of the quartzites to the schists have not been ascertained. The schists and quartzites of this area are similar in every way to the series of rocks exposed in the upper part of the Animas Canyon and in adjacent portions of the Quartzite or Needle Mountains, where they have been referred to the Algonkian by Emmons and Van Hise. The quartzite of the Rico Mountains is directly along the strike of the great quartzite belt in the Animas Canyon and Needle Mountain area.

Jaggar,[3] in connection with the discussion of the laccoliths of the northern Black Hills, incidentally refers to the structure of the Algonkian. Its lamination abuts abruptly against the hard basal Cambrian quartzite or the conglomerate, and has a fairly uniform strike of north-northwest. The Algonkian surface is seen to be warped.

[1] "Metamorphic Formations of Northwestern California," by OSCAR H. HERSHEY, *American Geologist*, Vol. XXVII, 1901, pp. 225–45.

[2] *Twenty-first Ann. Rept. U. S. Geol. Surv.*, Part II, 1901, pp. 37–78; with geological map.

[3] "The Laccoliths of the Black Hills," by T. A. JAGGAR, JR., *Twenty-first Ann. Rept. U. S. Geol. Surv.*, Part III, 1901, pp. 171–303.

Hills[1] describes the geology of the Walsenburg Folio of Colorado.

The principal mass of the Greenhorn Mountains consists of coarse and fine-grained granites and gneisses, hornblende, mica, and chlorite-schist, and subordinate masses of garnet-and epidote-schist, and occasional vein-like bodies of coarse pegmatite. The schistose rocks are more prominent at the southern extremity of the mountains than elsewhere, while the granite and gneissic rocks are more prominent in the main mass toward the culminating point.

Their origin probably dates back to the Archean period. No further correlation is attempted.

Watson[2] describes the granitic rocks of the Piedmont Plateau of Georgia and concludes that they were not all contemporaneous in origin. Some of them are pre-Cambrian, while others may possibly be later in age. However, the youngest acid intrusives could not have been later than, if as late as, the last great Appalachian disturbance or uplift.

Kemp, Newland and Hill[3] further discuss the geology of Hamilton, Warren and Washington counties, extending the observations noted in previous reports to the west and south.[4] The additional points of interest are the occurrence of anorthosites in Johnsburg, in Warren county, the southernmost exposure yet known in the eastern mountains, and "the increasing certainty of the existence of sedimentary gneisses in Fort Ann and Johnsburg townships."

[1] "Walsenburg Folio, Colorado," by R. C. HILLS, *Geol. Atlas of the U. S.*, No. 68, 1900.

[2] "The Granitic Rocks of Georgia and their Relationships," by THOMAS LEONARD WATSON, *American Geologist*, Vol. XXVII, 1901, pp. 199-225.

[3] "Preliminary Report on the Geology of Hamilton, Warren and Washington Counties," by J. F. KEMP, D. H. NEWLAND, and B. F. HILL, *Eighteenth Ann. Rept. State Geologist of New York*, published in *Fifty-second Rept. N. Y. State Museum*, Vol. II, 1900, pp.141–62; with geological maps.

[4] For general discussion of classification of geology of these counties see *Rept. of the New York State Geologist* for 1897, published in *Fifty-first Ann. Rept. New York State Museum*, Vol. II, 1899, pp. 499–553. Summarized, JOUR. GEOL., Vol. IX, 1901, p. 444.

Smyth[1] maps and describes the geology of the crystalline rocks in the vicinity of the St. Lawrence River in the towns of Alexander, Clayton, and Theresa, in Jefferson county, together with portions of Rossie and Hammond in St. Lawrence county. The crystalline rocks of the district are discriminated on the map as granite, granite-gneiss, granite-gneiss with much schist and quartzite, schists and quartzites with much granite-gneiss, schists and quartzites of limestone series, and crystalline limestone. This classification indicates the close association of the various rocks in the field. Under the term schists are classed a variety of rocks, such as quartzite, hornblende and mica schists, hornblende, pyroxene, and mica gneisses, etc., of both igneous and sedimentary origin. The gneiss formation is not a unit, but rather a complex, so far as age is concerned. It is the most widespread of the pre-Cambrian rocks. There is abundant evidence that the granite and granite-gneiss are for the most part younger than the schists and quartzite. The granite has a close genetic relation to the granite-gneiss and is identical with a part of the latter. The granite may be the youngest member of the granite-gneiss complex. The quartzite may have a thickness as great as 500 feet.

Kemp and Hill[2] report progress of work on the pre-Cambrian formations in parts of Warren, Saratoga, Fulton, and Montgomery counties.

Cushing[3] maps and describes the geology of Rand Hill and vicinity, Clinton county. The basal rocks are gneisses of the Dannemora formation occurring in the southwestern portion of the area. These are of doubtful origin, but probably mostly

[1] "Geology of the Crystalline Rocks in the Vicinity of the St. Lawrence River," by C. H. SMYTH, JR., *Nineteenth Ann. Rept. State Geologist of New York*, published in *Fifty-third Ann. Rept. N. Y. State Museum*, Vol. I, 1901, pp. 185–204; with geological map.

[2] "Pre-Cambrian Formations in Parts of Warren, Saratoga, Fulton, and Montgomery Counties," by J. F. KEMP and B. F. HILL, *Nineteenth Ann. Rept. State Geologist of New York*, published in *Fifty-third Ann. Rept. N. Y. State Museum*, Vol. I, 1901, pp. 121–135; with geological maps.

[3] "Geology of Rand Hill and Vicinity, Clinton County," by H. P. CUSHING, *Nineteenth Ann. Rept. State Geologist of New York*, published in *Fifty-third Ann. Rept. N. Y. State Museum*, Vol. I, 1901, pp. 139–182; with geological map.

igneous. Intrusive in them are undoubted igneous rocks—gabbro, anorthosite-gabbro, augite-syenite, syenite and dikes of syenite and diabase.

C. K. LEITH.

MADISON, WIS.

THE *Summary Report of the Geological Survey Department of Canada* for the year 1901 is a paper-bound volume of 270 pages, giving a concise outline of the work done during the year. The volume is issued in order to give to the public, without delay, the results of the year's investigations in different parts of the Dominion. The rapidly increasing mining industry of the country makes it very desirable that the information in possession of the Survey should be immediately available, whereas the full annual reports are, as a rule, two or more years behind the field work. During the last three years the Canadian Survey has lost a number of its men by death and resignation. The death of Dr. G. M. Dawson, late director, was a severe loss, and the resignation of such men as J. B. Tyrrel, A. P. Low, J. McEvoy and R. W. Brock leaves places which the younger appointees are not yet able to fill. Dr. Robert Bell, formerly deputy director, has been appointed acting director. The present staff numbers fifty-four.

During the year 1901 thirty-one parties were in the field, and work was done in each of the seven provinces and in the territories of Alberta, Yukon and Keewatin. R. G. McConnel and Joseph Keele continued the work in the Yukon field. Considerable searching has been done in the hope of finding the lodes from which the gold of the placers was derived. Auriferous quartz veins cut the igneous and clastic schists which are so abundant in the Yukon valley. As a rule, the veins, though numerous, are too small and discontinuous to warrant mining operations. The schists are also auriferous in places. R. A. Daly acted as geologist with the Canadian commission co-operating with the United States commission in locating the British Columbia section of the international boundary. The predominant rocks of the Coast Range were found to be metamorphic sediments, of which but few strata were fossiliferous. The mountain forms are regarded as erosional rather than constructional. Erosional features characteristic of the work of Alpine glaciers—cirques, cols, rock basins, ampitheaters, and deep re-entrants—are abundant. The existing glaciers are small, and there is no indication of general glaciation having prevailed in the belt. R. W. Brock worked in the

Boundary Mining District of British Columbia. The rocks of the district are largely eruptives and intrusives, consisting of greenstones, granites, tuffs, and lava, though older sediments, consisting of limestones, argillites, quartzites, and other metamorphic rocks have been caught up and included in the igneous flows. The region is wholly within the area covered by the Cordilleran ice sheet. The striæ show that the movement was mainly S. 30° E. Assorted glacial materials are very abundant, and terracing is very prominent, often reaching a height of 2,000 feet above the present valley levels. The ore bodies are of large size, but irregular in form and usually of low grade. They occur in all rocks except the newest, and mineralization has extended, with gradually decreasing richness, far into the country rock. Deposits within the limestones or the greenstones and at the contact of the two, are of most frequent occurrence. The vein minerals are chiefly magnetite, pyrrhotite, chalcopyrite, marcasite, arsenopyrite, and micaceous hematite, with more or less galena, sphalerite, and molybdenite. Magnetite is never abundant where pyrrhotite is prominent. The values are principally in copper, gold, and silver. The smelters at Grand Forks and Greenwood have been working steadily, but the pyritic smelter at Boundary Falls has not yet been blown in. W. W. Leach continued the examination of the Crow's Nest coal fields, which lie on the eastern border of British Columbia. The main area covers about 230 square miles, has twenty-two distinct seams with a total thickness of 216 feet, of which 100 feet is workable coal of excellent quality. The smaller, or Green Hills area, covers about seven square miles and contains 79 feet of workable coal in seven seams. L. M. Lambe resumed his work on the Cretaceous rocks of the Red Deer River, Alberta, and succeeded "in securing a large collection of chelonian, dinosaurian, crocodilian, fish, primitive mammalian, and other vertebrate remains of considerable value." Two Chelonians — *Trionyx foveatus* and *Trionyx vagans* — are figured and described. William McInnes worked on the pre-Cambrian formations between Lakes Superior and Manitoba. "The primary object of the season's work was to trace with greater accuracy the Sturgeon Lake gold-bearing belt and to work out the geology of an area lying to the southeast of the eastern half of Lac Seul." All of the important Huronian areas of this region are now mapped. Some promising mineral lands are being developed. A. W. G. Wilson spent the summer in the region west of the Nipigon river and lake. The rocks of the area studied belong to the Laurentian, Huronian, and Animikie

series. The Laurentian rocks consist of gneisses and granites with some schists; the Huronian, of ferruginous quartzite interbanded with hematite of good quality and varying in character from soft red to specular. The Animikie formation is the most widespread. A deep red dolomite, varying from a rather heavy bedded, compact, fine-grained rock to a coarser shaly variety, is the most important lithological unit. Associated with the dolomite is a highly ferruginous dolomitic sandstone which locally carries angular masses of quartz. Conformably overlying the red dolomite, on the Upper Spruce river, is a fine-grained, non-fossiliferous, greenish-gray shale, which is capped by fifteen feet of trap. Trappean flows, probably gabbroid, occasionally reaching a thickness of 300 feet, overlie the sediments for the most part, but are in places interbedded with them. In the eastern half of the Nipigon area the Huronian schists pass into jasper and hematite and form three iron ranges, one north and two south of Sturgeon river. Animikie traps are abundant in this area, and show about the same relations to the sedimentary series as in the western half. The explorations of D. B. Dowling in the region to the west of James bay have shown that the Paleozoic area beginning at the southern extremity of James bay extends uninterruptedly along the coast to cape Churchill in Lat. 59° N. The rocks of the newly explored area in the angle between James and Hudson bays are of Silurian age. To the southwest of Cape Henrietta Maria is a considerable area of Animikie rocks consisting of ferruginous slates and jaspers capped by trap.

Work in the vicinity of Lake Abitibi near the Ontario-Quebec boundary resulted in the more accurate mapping of the pre-Cambrian rocks. A. E. Barlow has added many important details to the reconnaissance work done in Denison, Graham and Creighton townships of the Sudbury mining region in 1890. The unaltered rock of the nickel-copper deposits is a quartz-hypersthene-gabbro or norite. The pyrrhotite, chalcopyrite, and pyrite were original constituents of the magma. In the process of slow cooling of these norite masses a species of differentiation resulted in the segregation of the sulphides "so that the final solidification saw the ore-bodies under very much the same conditions as at present obtain." Associated with the norite in the ore-bearing ranges are micropegmatites which are undoubtedly differentiated portions of the nickel-bearing eruptive, as there is a perfect transition from one rock type to the other. There are three distinct bands of the norite and associated micropegmatites. Of these

the southern, having a length of thirty-two miles and an average width of two miles, is the most important, though the others are not without promise. F. D. Adams returned to his work in the pre-Cambrian area of eastern Ontario. Two maps, covering about 4,200 square miles, have been prepared. The northern half of the area is occupied by granite-gneiss (probably equivalent to Logan's fundamental gneiss) while the rocks of the southern area are chiefly ancient sediments, largely limestones, resting on the gneissic series, but invaded, brecciated, and altered by it. Bathylithic masses of gneiss occur in both the granite-gneiss and the ancient sedimentary areas. In the southeastern portion of the area, associated with comparatively unaltered limestones, are masses of amphibolite and other foliated rocks, with an occasional band of conglomerate. The nepheline syenite of the southern portion of the area seems to have some genetic connection with the limestones and with the granites. Intrusions of gabbro are found associated with the amphibolites. In southwestern Ontario, R. Chalmers made a reconnaissance survey of the superficial deposits, and has recorded some observations relative to recent changes of the level of Lakes Huron and Erie. He also gathered data bearing on the salt, oil, and gas industries of that part of the province. In eastern Ontario R. W. Ells has made a re-survey of the Paleozoic formations about Kingston with a view to determining the age of certain limestones and shaly and arkose sandstones forming the basal strata of the sedimentary series. Murray (*Geological Survey of Canada*, 1852–3) regarded the limestones as of Black River age and the sandstones as of Potsdam. The apparent conformity of the two led later workers to suggest that the sandstones were a local development of the Black River. Ells finds abundant proofs of the Black River age of the limestones. As to the sandstones, though no conclusive proofs were found, he inclines to the view of Murray. He gives brief notes on the economic products of the area. Of these the more important are iron, mica, feldspar, marl, and building-stone. The Survey has planned the careful petrographical study of the rocks of the range of volcanic hills which crosses the St. Lawrence valley in the vicinity of Montreal. O. E. Le Roy has completed the work on Rigaud Mountain and is at work on the rocks of Beloeil. Dr. Adams will soon publish a description of Mount Johnson, and he and Professor Harrington are at work on the petrography of Mount Royal. J. A. Dresser finds Shefford Mountain to be composed of essexite, nordmarkite, and pulaskite. Work on Anticosti island confirms the general features of

the report of Richardson in 1856, and the account in the *Geology of Canada*, 1863. Abundant evidence shows that the island is gradually rising. Professor Bailey continued his work on the Paleozoic rocks of southern New Brunswick. Some areas west of St. John river, formerly mapped as Ordovician, on lithological grounds, are found to contain a rather meager Silurian fauna. Similar areas east of the river are probably of the same age. A systematic examination of the Carboniferous strata of New Brunswick, with a view to the discovery of workable coal has not afforded satisfactory results. Some reconnaissance work was done in Prince Edward Island by L. W. Watson. H. Fletcher finds that the sedimentary rocks about the Basin of Mines include representatives of all the Paleozoic groups and the Triassic and the Pleistocene. Igneous rocks are abundant, and include the Triassic traps and the intrusive masses of gray granite and gray diorite. The examination of the outcrops of the Horton series has failed to afford data by which its true position could be determined. It is evident, however, that it is below strata corresponding to the Keokuk-St. Louis. But some would place it near the base of the Devonian. E. R. Fairbault worked on the structural geology of the Cambrian gold-bearing slates and quartzites. The auriferous quartz veins in the area examined follow the contact of the bedded slates and quartzites. In places the folding has caused the development of saddle reefs, but the larger number of veins are on the limbs of the anticlines. G. F. Matthew presents in tabular form the results of his study of the Cambrian rocks of Cape Breton. He shows the completeness of the Cambrian record of the maritime provinces and correlates the formations with those of Great Britain. Extended notes are added on the particulars of the faunas. Dr. Hoffman reports briefly on the chemical and mineralogical work of the Survey. The substantial progress of the mineral industries is shown in the report of E. D. Ingall. A very valuable feature of the report is the index maps of the various provinces showing the areas covered by the various maps published and in preparation, and giving dates of the reports in which the areas are described. J. F. Whiteaves reports on the work in Paleontology.

Some of the individual reports seem to indicate lack of experience both in the prosecution of the field work and in the preparation of the report. The smallness of the parties and the large areas covered by some of them, make it impossible to do more than hasty reconnaissance work.

R. D. GEORGE.

Bibliography and Catalogue of the Fossil Vertebrata of North America. By OLIVER PERRY HAY. Washington: Bulletin of the United States Geological Survey, No. 179, 1902. Pp. 868.

VERTEBRATE palæontologists, not only of America, but of the world, are under obligations to Dr. Hay for his very useful bibliography and catalogue of North American fossil vertebrates. Only he who has attempted something of the sort, or who has toiled for many hours trying to find what Cope has written upon some given subject — and there are few subjects in vertebrate palæontology that he has not written about — will appreciate, not only the vast amount of painstaking labor that has been involved in the production of the work, but also its value as a time saver. The work is as complete and accurate as any one could expect it to be. Very few American papers are omitted, so far as the writer can discover, and he has discovered but few wrong references, not as many as might be expected from the mere mechanical execution of the book and its proofreading. The work is an indispensable necessity for every student of vertebrate palæontology, for which he can not be too grateful; and it is much more than the title indicates.

There are some, however, who will not wholly agree with the author in the many changes he has made in nomenclature — changes that are not always consistent, but which, while detracting somewhat from the usefulness of the work as a guide, do not affect it as a tool. Such long-established names as *Ichthyosaurus*, *Pterodactylus*, *Mastodon*, *Dicotyles*, *Oreodon*, *Lacertilia*, *Ophidia*, etc., have been ruthlessly decapitated on the score of priority, which sometimes, as in the case of *Pterodactylus*, is a little strained. The older French writers persistently transformed technical zoölogical terms into the vernacular, and doubtless Cuvier intended *Pterodactylus* as the name of the flying reptiles. *Basilosaurus*, though expressing a falsehood, and contrary to the best canons of nomenclature, he accepts in place of the well-known *Zeuglodon*. He refuses to accept *Dinocerata* in place of the wrongly-formed *Dinocerea*, though the latter term was rejected by its author, and yet changes *Toxochelydæ* into *Toxochelyidae*. He accepts *Deinodon* as distinct from *Dinodon*, but rejects *Deinosauria* in favor of *Dinosauria*. As a purist and priorist he goes too far, and becomes involved in difficulties, as is always sure to be the case. Surely it is allowable to correct manifestly wrongly spelled or wrongly Latinized names. But these opinions of the author one need not follow unless he chooses, and he has done a service in calling attention to these trivial but annoying matters of

dispute. One does not always see how the author has been guided in the selection of papers by foreign writers. From the list of over one hundred titles of papers published by Smith Woodward prior to 1900, sixty-nine are recorded. We can only be thankful that so many are given.

The geological survey is to be congratulated upon the publication of the work ; but we cannot help wishing that the printer had left the leaves untrimmed.

S. W. W.

Evolution of the Northern Part of the Lowlands of Southeastern Missouri. By PROFESSOR C. F. MARBUT. *The University of Missouri Studies*, Vol. I, No. 3 (Columbia), July, 1902. viii + 63 pages; plates I–VII.

THE paper is of more than usual interest to physiographers in that it presents in a comprehensive way the history of an extremely interesting locality. It is divided into Parts I and II, the former treating of the geography and geology of the region, and the latter of its physiographic development.

The writer abandons his former ideas of the origin of Crowley's Ridge,[1] and agrees, in the main, with the views of Dr. Branner, published several years ago, while state geologist of Arkansas.[2] It is shown that the lowland north and west of Crowley's and Benton Ridges, which is spoken of in the paper as the Advance lowland, was formed by the Mississippi at a time when it turned westward at the present site of Cape Girardeau and flowed past Delta, Poplar Bluff, and Neelysville, Mo., and Pocahontas, Powhattan, and Newport, Ark. While the Mississippi was forming the Advance lowland, the Ohio was eroding the broad valley between the eastern edge of Crowley's Ridge and the uplands of western Tennessee, and which the author calls the Cairo lowland.

While the Mississippi is the larger of the two streams, it has twice been captured by the Ohio. The capture of the larger stream by the smaller was made possible by the latter having the lower flood plain. The first capture was effected by a small tributary of the Ohio, working its way headward, through what was then a continuous ridge separating the two great rivers, along or near the present course of Little River; the second, by another small tributary working its way northward from

[1] *Proc. Bos. Soc. Nat. Hist.*, Vol. XXVI (1895), pp. 479–88.

[2] *Ann. Rep. Geol. Sur. Ark.*, Vol. II (1889), preface, p. xiv.

the present site of Commerce to where Gray's Point now stands. As a result of this, the Mississippi abandoned the Advance lowland at its eastern end and assumed its present course.

Other cases of capture of smaller streams are described in detail, which make interesting reading for the student of physiography.

The time of the lowland formation was the interval between the first and second glacial epochs.

Altogether it is an admirable piece of work. There are two points of courtesy, however, upon which the paper is open to some criticism: The discrediting of the published views of Dr. Branner upon the subject of the paper, and the underestimating of the maps of the region, published by the Mississippi River Commission. When in 1895 the author advocated a different theory regarding this drainage,[1] Branner's views were duly considered and promptly upset; now that Branner is found to be correct, his theory of the origin of Crowley's Ridge is spoken of as being "merely a statement of the popular view." The true theory of the ridge's history may be the popular one in Missouri, but the present writer has reason to believe that it is not the popular one in Arkansas even today. Again, Professor Marbut says that Dr. Branner's statements "lay no claim to scientific completeness." This is true; but it should be noted that Dr. Branner published his ideas, not in the body of the report on Crowley's Ridge, but in the preface to the report. The report itself was written by Professor Call, an assistant on the Arkansas Geological Survey, with whose ideas as to the origin of the ridge Dr. Branner did not agree; and not agreeing, justice to himself required him to say so, but at the same time good taste and expediency forbade a full discussion of the matter at that time and place. The present writer happens to know that the data collected by the late Arkansas survey on the history of Crowley's Ridge would fill a good-sized volume. While Dr. Branner's treatment of the subject made no pretense of being exhaustive, his statements were based upon a large amount of data at his command. The author likewise says that when he undertook the work on the region "no sort of topographic map of this part of the lowlands was in existence." The map published with the Crowley's Ridge report of the Arkansas Geological Survey, and the map of the Mississippi River Commission from which the Arkansas map was largely compiled, so far as their portrayal of the physiographic history of the region goes, are in all essen-

[1] *Loc. cit.*

tials relating to the questions discussed, like that published by Professor Marbut, Plate VI of his paper.

Again, the present writer wishes to express his appreciation of Professor Marbut's paper as an interesting and detailed account of physiographic changes, the main features of which were already known.

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Ensayo de una bibliografia historica i jeografica de Chile. Por NICOLAS ANRIQUE R. I L. IGNACIO SILVA A. Santiago de Chile. 1902. 8vo, xix + 679 pages.

THIS work is of the first importance to all students of the history, geography, and geology of Chile. It contains 2,561 titles, to many of which are added brief but valuable annotations. The bulk of the works listed are in the Spanish language, but there are many in German, French, and English. The first 996 titles relate to the history of Chile; the remaining 1,565 relate to its geography, including topography, hydrography, seismology, meteorology, travels, geology, paleontology, and mineralogy. The introduction to the second part contains a sketch of the physical geography of Chile. The author observes that the number of Chilean volcanoes has been greatly exaggerated. A list of them is given, with their latitudes, elevations, and dates of last eruptions. This list mentions forty volcanoes, for several of which no eruptions have been reported. The second part of this introduction devotes eleven pages to the meteorology and climate, under which are included earthquakes, the most important of which are listed. The third part of the introduction treats briefly of ethnographic geography. In spite of numerous oversights and omissions this is one of the most valuable publications made of late years in Chile and it is to be hoped that it will be turned to abundant account by our students of both political and natural history.

J. C. BRANNER.

STANFORD UNIVERSITY,
California, November 4, 1902.

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